(4)

WSRL-0566-TM

AR-005-348

DEPARTMENT OF DEFENCE

DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION
SALISBURY

WEAPONS SYSTEMS RESEARCH LABORATORY

SOUTH AUSTRALIA

TECHNICAL MEMORANDUM

WSRL-0566-TM

ENGINES FOR MINI-RPV XM-1A

E.H. BARNARD-BROWN

Technical Memoranda are of a tentative nature, representing the views of the author(s), and do not necessarily carry the authority of the Laboratory.

Approved for Public Release

COPY No.

JANUARY 1988

UNCLASSIFIED

AR-005-348

DEPARTMENT OF DEFENCE

DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION

WEAPONS SYSTEMS RESEARCH LABORATORY

TECHNICAL MEMORANDUM

WSRL-0566-TM

ENGINES FOR MINI-RPV XM-1A

E.H. Barnard-Brown

SUMMARY

There were very few light-weight reciprocating engines in the five to ten horsepower range existing in Australia or overseas when a programme of research and exploratory development of the techniques required to operate unmanned airborne vehicles from a remote base station started in 1975. Those that did were generally single cylinder engines which are difficult to balance over the speed range necessary for mini remotely piloted vehicle (RPV) operation. A twin cylinder Kolbo D238 engine and a larger Herbrandson Dyad 160 engine were flown. When fitted with a locally developed capacitor discharge ignition system, both these engines performed reliably in flight trials of the mini-RPV XM-1A. However, the Kolbo engine had insufficient power for aircraft with a take-off mass of more than about 35 kg.

This memorandum records the experience and test results gained at Weapons Systems Research Laboratory (WSRL) on small engines from its mini-RPV programme conducted during 1975 to 1981.

POSTAL ADDRESS: Director, Weapons Systems Research Laboratory,
PO Box 1700, Salisbury, South Australia, 5108.

UNCLASSIFIED

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

1. INTRODUCTION

An in-house programme of research and exploratory development of the techniques required to operate unmanned airborne vehicles from a remote base station began in 1975(ref.1,2). Aeroballistics Division (AD), now Weapons Division, undertook to support Weapon Systems Division (WSD), now Combat Systems Division, by the provision of test vehicle airframes, engines, auto-pilot, power supplies, regulators and test pilots. This programme was terminated in 1981 and this memorandum records the experience and test results gained including those from 64 mini-RPV flights lasting a total of 7½ h.

Preliminary design of the 3 m wing span mini remotely piloted vehicle (RPV) to carry the WSD equipment indicated a take-off mass in the range 38 to 45 kg and an engine power requirement in the range 3 to 4.5 kW(ref.3). During the programme, the take-off mass increased to 54.4 kg for the aircraft XM-1A/2 carrying WSD equipment and to a maximum of 58.9 kg for the test aircraft XM-1A/3. Consequently, the engine power requirement increased substantially. The XM-1A mini-RPV test vehicle is shown in figure 1.

2. ENGINE SURVEYS

2.1 Initial assessment of engine market

At the start of the programme, a survey of the local market showed that the range of model aircraft engines ended at about 1 kW, 10 cc capacity, since the legal upper limit in model aircraft mass is set at 5 kg by the Department of Transport. Several motor cycle engines in the 50 to 100 cc range were available but had casings integrated with the gear box. An 6.5 kW McCulloch MC 91 engine (figure 2) was purchased for general assessment but was found to be too large for the light XM-1A airframe. Vibration associated with the single cylinder design was quite excessive and it was decided to investigate the overseas market for a multi-cylinder engine in the 3 to 4.5 kW category.

Two engines which appeared suitable, were the Ross six and the Kolbo D238 (figure 2). Orders were first placed for the Ross six which was advertised as having low vibration characteristics, good power-to-weight ratio and low fuel consumption (see Appendix I for the general specification). Due to company changes and eventually cancellation of production, only one engine was obtained after a lengthy acquisition time and it was not flown. Consequently, this engine is not discussed in this memorandum. The remaining choice was the Kolbo D238 horizontally-opposed twin-cylinder 3.7 kW engine of high power-to-mass ratio but rather high stated fuel consumption and cost. However, in the absence of other contenders, two engines were purchased in 1975, two more in 1977 and a fifth in 1978. A test rig (Appendix II) was developed to assess their performances.

2.2 Re-assessment of engine market

The Kolbo D238 engine was shown to have insufficient power for an aircraft mass in excess of about 40 kg(ref.4,5) and a search for more powerful engines was made.

2.2.1 Single cylinder engines

During the initial design and development of the airframe and the testing of the Kolbo D238, there had been a few additions of small single cylinder engines on the local market. However, of those listed in Table 1, only the Stihl 042 chainsaw engine was close enough to the Kolbo D238 in power to be considered. A preliminary assessment of this engine (as incorporated in a chainsaw) showed that although it was reasonably smooth at full throttle, it was much less so at idling speed. The estimated stripped down mass was 2.7 kg for 3.3 kW against 2.1 kg for over 3.7 kW for the Kolbo D238. This engine was considered to have insufficient power to warrant further investigation.

2.2.2 Twin cylinder engines

In the meantime, more data was obtained on several American engine developments. The engine used in the Navy STAR Delta, the M262, was constructed from two McCulloch MC101 engines geared together and was known to have developed problems on at least two occasions. In any case such an engine was too large for XM-1A consideration.

Another twin cylinder engine, the Dyad 160, rated at about 7.5 kW (10 HP) was developed by DH Enterprises, California, based on two Stihl 80 cc chainsaw engines in a horizontally opposed configuration. An initial general assembly drawing showed a three-piece crankshaft pressed together to allow the use of one-piece connecting rods and bearings. What appeared undesirable, however, was the use of only three shaft support bearings, inferring the transfer of bending loads across one of the pressed shaft joints. Limited WSRL experience showed that pressed joints tend to deform if subjected to any abnormal bending overloads. Following an enquiry for further details on the Dyad 160 engine, a more recent drawing was received showing four support bearings for the three-piece shaft. Performance and fuel economy figures looked acceptable and the electronic spark ignition system was designed to minimise RF interference problems. Four of these engines were purchased in 1978/79 to replace the Kolbo D238 on the XM-1A aircraft with higher take off masses.

Information on the Teledyne Continental Mk II RPV engine showed it to be excessive in mass at 10 kg and power at 15 kW for the XM-1A requirement. Also it was not, at that time, available on the market.

In the UK, some engine development was carried out by Kerslake Engineering Co on a 15 kW horizontal twin with the potential for the development of four and six cylinder versions producing 30 kW and 45 kW respectively. Again these were all larger than required.

Westlands, who were engaged in the helicopter RPV (Wasp) development, were using the Kolbo D238 engine but had a failure due, according to the manufacturer, to using synthetic oil lubricant when converting from alcohol-oil glow plug ignition to petrol-oil spark ignition.

2.2.3 Ignition

It was noted that many overseas mini-RPV's were using petrol-oil for fuel economy and capacitor discharge spark ignition for reliable low vibration engine operation. Spark ignition, however, requires careful screening of all components to prevent interference with other electronic systems on the aircraft. This information confirmed the validity of our decision to use a capacitor discharge ignition (CDI) system (see Section 3.5.1).

3. KOLBO D238 ENGINE

3.1 General

A size comparison of the Kolbo, McCulloch and Ross engines is shown in figure 2. Appendix III records the specification given by the manufacturer for the Kolbo D238 engine and the assembly drawing is shown in figures 3 and 4. The size, power-to-mass ratio and configuration (horizontally opposed - low vibration design, low drag frontal area) were all suited to the initial XM-1A engine requirement. Simple glow plug ignition with lubrication by fuel-oil mixture inferred simplicity of the overall system.

3.2 Confirmation tests with glow plug ignition

Initial ground tests were carried out and it was confirmed that with the correct mixture control settings, both the 2000 rev/min idle and 6000 rev/min full throttle engine speeds with a 508 mm x 457 mm (20 x 18 inches) pitch propeller could be achieved in still air (static) conditions with the recommended glow plugs and using the recommended fuel mixture of 80% methyl alcohol, 10% nitro-methane and 10% castor oil(ref.6). Approximately 120 N static thrust was measured on the engine test rig with the 508 mm x 457 mm propeller turning at 6000 rev/min. This again matched the figure given by the manufacturer. Measurements of torque could not be obtained initially due to the higher than expected vibration levels (15 g when measured on a payload package in the airframe), see 17/11/75 in Appendix IV.1.

3.3 Performance measurements

The Kolbo D238 engine was mounted on the test rig (Appendix II) which measures torque (balance weights at known torque arm), revolutions per minute (electronic-optical pick-off or mechanical friction-drive revolutions per minute counter), thrust (strain-gauged cantilevered vertical beam fixed to 'floating' engine mounting tray) and fuel consumption (fuel volume vs time). The engine test results for the five Kolbo D238 engines are included in Appendix IV.

The original two engines (Serial Nos. Nil and 0015) had to have their original pistons replaced with the 10% thicker pistons made locally at Salisbury, see Appendices IV.1, IV.2 and V. The other two (Serial Nos. 0031 and 0032) had domed pistons and modified porting supplied by the Kolbo Corporation. Problems encountered with the Kolbo engine, especially with glow plug ignition, are discussed in Appendix V.

3.4 Flight trials with glow plug ignition

After verification of the engine performance, the engine was fitted to the XM-1A aircraft (figures 5 and 6) with a 27 MHz Kraft radio control system for line-of-sight flying.

Acceleration tests were carried out on the Edinburgh runway which showed that the engine with a 508 mm x 457 mm propeller could accelerate the aircraft up to 14 m/s in about 35 m for an aircraft mass of 28.7 kg. Following a number of ground acceleration runs, several lift-offs were made at speeds in the region of 11 to 15 m/s in 30 to 40 m distance with headwinds averaging 5 m/s (9 to 10 kn).

During the first flight, the engine stopped at cruising speed probably due to a change of mixture control setting under vibration. In the ensuring forced landing, the tail-booms struck the ground during flare-out, apparently overstressing the boom roots which subsequently failed on the fourth flight during an abnormal pitching motion, possibly caused by radio interference. The second and third flights were uneventful.

To improve take-off performance, the propeller was then changed to a 508 mm x 355 mm propeller which resulted in maximum power of 3 kW at 7000 rev/min and a thrust of 108 N. Five flights lasting a total of 14 min flying time were made with 2 aircraft powered by the Kolbo D238 engine with glow plug ignition. The maximum take-off mass was 35 kg. These flights are listed in Table 2 and are summarised in Table 3.

3.5 Ground tests with electronic spark ignition

3.5.1 General

The decision to go to spark ignition was not taken lightly because of the additional complication and possible interference of such a system with the payload electronics. However, there seemed no other choice and it was then known that overseas RPV's with larger engines were using spark ignition with fully shielded components.

3.5.2 Short-term development for ground tests

In order to assess the effect of capacitor discharge ignition (CDI) on engine behaviour, an ignition system was built based on the standard 'Kettering' system as used in motor vehicles. It was useful only for bench tests since it was heavy, unscreened and consumed excessive power (30 to 35 W). An electronic spark timing control unit was also designed and built giving linear retardation from 5° to 30° before top dead centre (TDC) from 2000 to 8500 rev/min. Tests run in a pressurised tube indicated that the voltage pulses dropped to too low a value at speeds above 5000 rev/min. The use of a 1 μF 600 V capacitor discharge system overcame this problem and the engine was run using CDI with a J6J Champion spark plug. Although the engine ran satisfactorily at 4000 rev/min, a speed of 5000 rev/min could only be maintained for about 1 min. Changing to J18Y 'hot' plugs decreased performance and it was found that J4J intermediate plugs were about optimum giving the expected 6000 rev/min. These initial tests were carried out using the same fuel mixture (80% methyl alcohol, 10% nitro-methane and 10% castor oil) as for the glow plug ignition. Unexpectedly, changes in spark advance from 5° up to 25° before TDC had little effect. It was considered that this could have been the result of a methanol fuel burning rate that is highly dependent on pressure. Spark ignition resulted in a significant reduction of vibration by achieving consistent and near equal ignition timing in the two horizontally opposed cylinders.

3.5.3 WSRL spark ignition system for airborne use

Several types of spark ignition systems were considered including self-oscillating and driven CDI, ringing choke CDI, magneto and transistor switched auto-transformer.

The CDI system(ref.7) chosen for flight trials is driven by a self oscillating convertor, is fully screened and uses an independent battery supply. It has been successfully flown many times in an aircraft controlled by 'Kraft' radio control equipment and three times in XM-1A/2 aircraft fully equipped with avionics including the data link digital control system. Figure 6 shows the CDI system mounted underneath the engine.

3.5.4 Kolbo spark ignition system

A CDI unit was developed by the manufacturer for his engine. Two units were purchased for assessment but were found to be unsuitable for XM-1A aircraft, as they were not screened to reduce RF interference.

3.6 Flight trials with CD ignition

After the fifth flight, the WSRL CDI system was used for all subsequent flights. This system overcame many of the problems experienced with glow plug ignition. 33 flights lasting a total of 4 h 4 min flying time were made with a take-off mass up to a maximum of 41 kg (see Tables 2 and 3).

The sluggish performance during these flights showed that the Kolbo engine had insufficient power for the mini RPV at a take-off mass of about 40 kg. However, the engine with capacitor discharge spark ignition performed very well and was much more reliable.

3.7 Fuel mixture

In choosing a fuel mixture, a compromise has to be reached between maximum achieveable power, lowest specific fuel consumption and adequate oil content for reliable lubrication. These balances are generally worked out by the manufacturer and the engine performance is quoted in respect to the recommended fuel mixture. However, there are two options depending on the emphasis on power or economy.

3.7.1 Maximum power mixture

A fuel mixture of 80% methyl alcohol, 10% nitro-methane and 10% castor oil was recommended by the manufacturer for the Kolbo D238 with a compression ratio of 6.2 to 1 and glow plug ignition. Measurements (Appendix IV) showed power levels of 2.8 kW (3.8 HP) at 6000 rev/min, rising to 3.8 kW (5.2 HP) at 8300 rev/min with corresponding fuel consumption of about 1.8 and 2.9 L/HP/h.

3.7.2 Maximum economy mixture

The manufacturer indicated that at least a 40% saving in fuel consumption could be realised by changing to 94.1% petrol - 5.9% petroleum oil mixture, increasing the compression ratio to about 8.3 to 1, and replacing the carburettor with one to cope with the fuel-air ratio change from 10.5 to 1 to 17 to 1. With these changes the petrol-oil mix would give 7% less power than the alcohol mix and it would be necessary to change to spark ignition to ensure ignition and to satisfactorily control the ignition timing.

3.7.3 Choice for XM-1A aircraft

Since the XM-1A was intended to be a test platform for mini-RPV experimental systems, there was no particular need to consider long flight times where fuel economy would have a major bearing on take-off mass and volume for fuel. Therefore, the higher power associated with the alcohol mix was chosen to allow for possible aircraft mass growth during system development. Glow plug ignition appeared the simplest method at the time of purchase but the reversal problem and high vibration levels due to poor timing, forced a change to spark ignition. A change of fuel from alcohol to petrol was not considered necessary for the short duration flights planned for the XM-1A trials.

3.7.4 Fuel change

The fuel mixture was changed, with the manufacturer's concurrence, from 80% methyl alcohol, 10% nitro-methane, 10% castor oil, to an 85%, 5%, 10% mixture to reduce the sensitivity to early ignition.

4. DYAD 160 ENGINE

4.1 General

The Dyad 160 twin cylinder horizontally opposed engine is shown in figures 7 to 10 and fitted to an XM-1A aircraft in figure 11. Appendix VI records the specification given by the manufacturer. Like the Kolbo D238, the configuration of this engine is suitable for the XM-1A aircraft. Based on our experience with the Kolbo engine, the WSRL CDI system was used for all tests and flight trials with this engine.

4.2 Performance measurements

Ground tests showed that if this engine was properly tuned, as discussed in Appendix VII, it performed very reliably. The results for the four engines are included in Appendix VIII.

4.3 Flight trials

The Dyad 160 engine had ample power to successfully fly XM-1A/3 at a take-off mass of 58.9 kg. The details of the 26 flights lasting a total of nearly 3 h are given in Tables 2 and 3. The premature stopping of the engine on the last three flights of XM-1A/2 was not investigated due to the termination of this RPV Task. The command and control system used for XM-1A/2 was very different from the simple system used for XM-1A/3 and the cause may be in that system rather than in the engine.

5. LOCAL ENGINE DEVELOPMENT

5.1 Local manufacture

Although WSRL was not able to finance mini-RPV engine development, discussions were held with several local manufacturers in the hope that they might have considered it worth risking an initial outlay to break into a possible new market area. Of the three companies contacted (Repco Research Laboratory, Burford and Noslen) only the latter produced a prototype engine based on four piston and cylinder sets from the single cylinder Webra Speed 61 model aircraft engine.

5.2 The Noslen Four

This prototype (see figures 12 and 13) based on the 10 cc Webra two-stroke glow plug ignition engine was run at speeds up to 13000 rev/min but developed a bearing failure while on the engine test rig. Appendix IX gives the test results for the 'Noslen Four' up to the time of failure.

Very low vibration was generated by the engine and although it has a total of 40 cc capacity compared with 62 cc for the Kolbo D238 it was thought that for a possible next generation of mini-RPV (XM-II), required to carry TV and laser designation test systems, a twin engined configuration could be considered. Two Noslen engines would give sufficient take-off power to cope with the heavier aircraft and would contribute significantly to overall reliability by providing the capability of flying the aircraft back to base if one engine failed in flight.

Even as a backstop to the Kolbo D238, two Noslen engines could easily be fitted to the booms of the XM-1A in tractor configuration with 355 mm (14 inch) propellers (limited by fuselage clearance). For this reason, low priority development of the Noslen engine continued until the Dyad 160 engine was obtained.

5.3 Longer term consideration

It will be evident that the choice of engine and airframe configuration for a mini-RPV depends predominantly on take-off mass and the mission flight time requirement. For test purposes, fuel economy is of little significance, but for mission applications, which are likely to require two hours or more flight duration, fuel economy becomes a significant factor in keeping take-off mass to a minimum. The longer the required flight time, the more significant fuel economy becomes in minimising total mass, and serious consideration would be given to increasing the basic engine mass to incorporate fuel saving capabilities. One possible change to improve fuel economy would be to use a four-stroke engine.

References 8 and 9 give information on RPV engines being developed at Aeronautical Research Laboratories in Melbourne.

6. CONCLUDING REMARKS

The engine most suitable for the WSRL XM-1A mini-RPV test vehicle with a take-off mass of about 55 kg was the Dyad 160 horizontal twin cylinder two-stroke engine with CDI spark ignition. This engine when tuned correctly performed very well and was very reliable. The Kolbo D238 engine with electronic spark ignition was suitable for a mini-RPV with a take-off mass up to about 35 kg.

7. ACKNOWLEDGEMENTS

The author wishes to acknowledge the effort expended on this RPV Task by Mr H.W. Evans, who supervised the initial work, and the assistance given by the staff of Field Experiments Group, especially Messrs J. Landreth, D. Watkins, O. Sillett and E. Richards, until their retirement and by Messrs M. Kennewell and B. Horrocks, in the preparation and testing of the engines and in flying the aircraft.

8. TERMINOLOGY

Appendix X lists the DSTO and RAAF Establishments referred to in this memorandum and, where appropriate, gives the changes, particularly name changes, since the events recorded took place.

Appendix XI lists the principal abbreviations used, other than standard abbreviations for units.

Generally metric units have been used in this memorandum but Imperial units, particularly horsepower (HP), have been included.

TABLE 1. GENERAL COMPARISON OF SOME SMALL 2-STOKE ENGINES

Name of engine	No. of cyl	Total capacity		Mass	Power max		RPM	Fuel consum	Propeller		Max. thrust	Fuel	Ign
		cc	in³	kg	HP	kW	max	L/h	Dia mm	Pitch mm	N	*	**
Webra Speed 61	1	10.0	0.61	0.57	1.0	1.3	12000	0.8	305	152	33	A	G
Ross Six	6	29.6	1.80	1.13	3.0	4.0	15000	1.4					G
Quadra	1	33.0	2.0	1.40	1.5	2.0	8000	0.7	457	152		C	M
Noslen Four ***	4	40.0	2.4	1.90	2.4	3.2	9000		432	152	93	A	G
Rosspower 3500	2	57.0	3.5	2.04	3.7	5.0	7200	1.8					G
Kolbo D238	2	62.0	3.8	2.10	3.7	5.0	7000	4.0	508	355	110	B	G
Rosspower 7000	4	116.0	7.1	4.10	7.5	10.0	9000	4.6					G
Kolbo D274	2	121.0	7.4	2.90	7.5	10.0	5600	6.7					G
Kolbo D2100	2	161.0	9.8	4.30	11.0	15.0		12.0					G
McCulloch MC91	1	118.0	7.5	6.30	6.5	8.7	8500	4.8					M
Stihl 031	1	48.0	2.9	1.80	2.4	3.2	12000					D	M
Stihl 042	1	68.0	4.2	2.70	3.3	4.5	11500						CDI
Dyad 160	2	161.0	9.8	4.10	7.5	10.0	8400	2.9	508	381	220	D	CDI

*

Fuel	A	B	C	D
Methanol	77%	80%		
Nitro methane	3%	10%		
Castor oil	20%	10%		
Petrol			95%	96%
Mineral oil			5%	4%
Density kg/L	0.778		0.816	

** Ignition

Glowplug = G
CDI spark = CDI
Magnetic spark = M

*** One-off experimental engine

TABLE 2. XM-1 RPV FLIGHTS

Flight No. & date	Air-craft No XM-1	Engine type & S No.	Take-off mass kg	CG %	Flight Time min	cumulative data: Flight & time h min	cumulative data: No. of flight	Comments
GLOW PLUG IGNITION								
One 20/2/76		Kolbo Nil	30.3	35.0	1	- 1	1	Engine stopped in flight. Heavy landing
Two 16/3/76		Kolbo 0015	32.3	36.1	4	- 5	2	Engine stopped in flight.
Three 25/3/76		Kolbo 0015	32.0	36.1	4	- 9	3	
Four 25/3/76		Kolbo 0015	32.0	36.1	4	- 13	4	Crashed after booms failed in flight.
Five 22/2/78	A/W1	Kolbo 0015	40.5	35.0	1	- 1	1	Crashed on final approach.
CDI IGNITION								
Six 02/5/78	A/3	Kolbo 0031	41.0	30.0	7	- 7	1	
Seven 22/5/78	A/3	Kolbo 0031	41.0	30.0	10	- 17	2	
Eight 22/5/78	A/3	Kolbo 0031	41.0	30.0	9	- 26	3	
Nine 22/5/78	A/3	Kolbo 0031	41.0	30.0	3	- 29	4	
Ten 22/5/78	A/3	Kolbo 0031	41.0	30.0	2	- 31	5	
Eleven 24/5/78	A/3	Kolbo 0031	41.0	30.0	9	- 40	6	
Twelve 13/6/78	A/3	Kolbo 0031	41.0	30.0	6	- 4C	7	
Thirteen 13/6/78	A/3	Kolbo 0031	41.0	30.0	3	- 49	8	
Fourteen 13/6/78	A/3	Kolbo 0031	41.0	30.0	2	- 51	9	
Fifteen 15/6/78	A/3	Kolbo 0031	41.0	30.0	8	- 59	10	

TABLE 2(CONTD.).

Flight No. & date	Air-craft No. XM-1	Engine type & S No.	Take-off mass kg	CG %	Flight Time min	cumulative data Flight & time h min	No. of flight	Comments
Sixteen 15/6/78	A/3	Kolbo 0031	41.0	30.0	5	1 04	11	
Seventeen 15/6/78	A/3	Kolbo 0031	41.0	30.0	7	1 11	12	
Eighteen 15/6/78	A/3	Kolbo 0031	41.0	30.0	4	1 15	13	
Nineteen 15/6/78	A/3	Kolbo 0031	41.0	30.0	7	1 22	14	
Twenty 15/6/78	A/3	Kolbo 0031	41.0	30.0	8	1 30	15	
Twenty One 15/6/78	A/3	Kolbo 0031	41.0	30.0	4	1 34	16	
Twenty Two 15/6/78	A/3	Kolbo 0031	41.0	30.0	6	1 40	17	
Twenty Three 19/6/78	A/3	Kolbo 0031	41.0	30.0	6	1 46	18	
Twenty Four 19/6/78	A/3	Kolbo 0031	41.0	30.0	3	1 49	19	
Twenty Five 19/6/78	A/3	Kolbo 0031	41.0	30.0	8	1 57	20	
Twenty Six 20/6/78	A/3	Kolbo 0031	41.0	30.0	5	2 02	21	
Twenty Seven 20/6/78	A/3	Kolbo 0031	41.0	30.0	3	2 05	22	
Twenty Eight 20/6/78	A/3	Kolbo 0031	41.0	30.0	7	2 12	23	
Twenty Nine 20/6/78	A/3	Kolbo 0031	41.0	30.0	4	2 16	24	

TABLE 2(CONTD.).

Flight No. & date	Aircraft No. XM-1	Engine type & S No.	Take-off mass kg	CG %	Flight Time min	cumulative data Flight & time h min	No. of flight	Comments
Thirty 20/6/78	A/3	Kolbo 0031	41.0	30.0	6	2 22	25	
Thirty One 20/6/78	A/3	Kolbo 0031	41.0	30.0	5	2 27	26	
Thirty Two 20/6/78	A/3	Kolbo 0031	41.0	30.0	9	2 36	27	
Thirty Three 21/6/78	A/3	Kolbo 0031	41.0	30.0	6	2 42	28	
Thirty Four 21/6/78	A/3	Kolbo 0031	41.0	30.0	2	2 44	29	
Thirty Five 21/6/78	A/3	Kolbo 0031	41.0	30.0	7	2 51	30	
Thirty Six 21/6/78	A/3	Kolbo 0031	41.0	30.0	5	2 56	31	
Thirty Seven 21/6/78	A/3	Kolbo 0031	41.0	30.0	8	3 04	32	
Thirty Eight 12/10/78	A/3	Kolbo 0032	41.0	30.0	-	3 04	33	Crashed on take off.
Thirty Nine 19/10/78	A/W1	Dyad 2	48.8	30.0	3	- 04	2	
Forty 19/10/78	A/W1	Dyad 2	48.8	30.0	2	- 06	3	Crashed after applying power.
Forty One 27/2/80	A/5	Dyad 3	48.4	30.0	11	- 11	1	
Forty Two 5/3/80	A/5	Dyad 3	48.4	30.0	2	- 13	2	

TABLE 2(CONTD.).

Flight No. & date	Air-craft No. XM-1	Engine type & S No.	Take-off mass kg	CG %	Flight Time min	cumulative data: Flight & Time h min	cumulative data: No. of flight	Comments
Forty Three 5/3/80	A/5	Dyad 3	48.4	30.0	3	- 16	3	
Forty Four 29/4/80	A/5	Dyad 3	48.5	30.0	6	- 22	4	Hard landing.
Forty Five 12/2/81	A/5	Dyad 3	51.0	30.0	1	- 23	5	Crashed after take off.
Forty Six 28/8/81	A/3	Dyad 3	44.7	30.9	1	3 05	34	
Forty Seven 7/9/81	A/3	Dyad 3	44.7	30.9	6	3 11	35	
Forty Eight 10/9/81	A/3	Dyad 3	48.1	31/0	5	3 16	36	
Forty Nine 16/9/81	A/3	Dyad 3	52.0	30.8	5	3 21	37	
Fifty 17/9/81	A/3	Dyad 3	52.0	30.8	7	3 28	38	
Fifty One 17/9/81	A/3	Dyad 3	54.5	30.8	5	3 33	39	
Fifty Two 18/9/81	A/3	Dyad 3	58.9	30.8	3	3 36	40	Highest take off mass.
Fifty Three 29/9/81	A/3	Dyad 3	58.9	30.8	10	3 46	41	Tyre shed on landing.
Fifty Four 29/10/81	A/3	Dyad 3	58.9	30.8	6	3 52	42	
Fifty Five 5/11/81	A/3	Dyad 3	58.9	30.8	7	3 59	43	

TABLE 2(CONTD.).

Flight No. & date	Aircraft No. XM-1	Engine Type & S No.	Take-off mass kg	CG %	Flight Time min	cumulative data		Comments
						Flight & time h min	No. of flight	
Fifty Six 20/11/81	A/3	Dyad 3	58.9	30.8	15	4 14	44	
Fifty Seven 15/12/81	A/2	Dyad 2	54.4	30.8	9	- 9	1	WSD equipped aircraft.
Fifty Eight 17/3/82	A/3	Dyad 3	58.9	30.8	17	4 31	45	
Fifty Nine 18/3/82	A/3	Dyad 3	58.9	30.8	9	4 40	46	
Sixty 6/4/82	A/3	Dyad 3	58.9	30.8	10	4 50	47	
Sixty One 7/4/82	A/2	Dyad 2	54.4	30.8	16	- 23	2	Engine stopped on landing.
Sixty Two 25/6/82	A/3	Dyad 3	58.9	30.8	14	5 04	48	
Sixty Three 30/6/82	A/2	Dyad 2	54.4	30.8	2	- 25	3	Engine stopped on low pass.
Sixty Four 12/7/82	A/2	Dyad 2	54.4	30.8	3	- 28	4	Engine stopped when aircraft recalled. Heavy landing

TABLE 3. SUMMARY OF ENGINE FLIGHT TIME

Engine		No. of flights	Total flights by engine type	Cumulative flight time			
				by engine		by engine type	
Type	Serial No.			h	min	h	min
Kolbo	Nil	1 (b)			1		
Kolbo	0015	4 (b)			28		
Kolbo	0031	32 (c)		4	4		
Kolbo	0032	1(a,c)	38	-	-	4	33(d)
Dyad	2	6 (c)			35		
Dyad	3	20 (c)	26	2	23	2	58

NOTES:
- (a) Crashed on take-off
- (b) Fitted with glow plug ignition
- (c) Fitted with CDI ignition
- (d) 4 h 4 min with CDI ignition

TABLE 4. THRUST FROM KOLBO WITH DIFFERENT PROPELLERS

RPM	THRUST N								
	508 x 457				508 x 355		480 x 457	419 x 457	381 x 457
	Kolbo		WSRL						
	Mean	Range	Mean	Range	Mean	Range	Value	Value	Value
2000	16	-	-	-	-	-	-	-	-
2500	22	-	-	-	-	-	-	-	-
3000	28	20-33	34	33-36	20	17-31	-	-	-
3500	40	37-50	34	36-51	31	26-44	-	-	-
4000	55	46-75	58	48-67	38	32-48	-	-	-
4500	66	59-80	71	60-82	48	42-60	-	44	-
5000	78	67-90	81	74-88	59	51-76	47	55	-
5500	94	83-111	97	88-105	72	55-87	82	67	-
6000	109	95-124	107	105-111	84	77-99	101	79	47
6500	-	-	-	-	95	90-100	-	92	57
6800	-	-	-	-	-	-	-	101	-
7000	-	-	-	-	110	-	-	-	68
7500	-	-	-	-	-	-	-	-	78
8000	-	-	-	-	-	-	-	-	89
8400	-	-	-	-	-	-	-	-	99

TABLE 5. THRUST FROM DYAD WITH DIFFERENT PROPELLERS

RPM	THRUST N										
	508 x 380 mm				508 x 355 mm				508 x 330 mm		
	Narrow tip chord		Wide tip chord		Narrow tip chord		Wide tip chord		Narrow tip chord		Wide tip chord
	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Mean	Range	Value
2500	21	18-25	-	-	20	-	-	-	-	-	-
3000	31	27-35	-	-	25	-	-	-	26	-	-
3500	39	25-49	41	38-49	38	34-49	38	36-40	35	32-39	35
4000	50	33-56	51	49-67	49	44-57	46	47-51	45	43-47	50
4500	65	55-73	69	59-87	61	57-64	64	62-65	56	54-60	59
5000	80	74-90	84	71-99	76	73-82	79	73-88	73	82-93	71
5500	95	88-108	102	90-110	90	83-100	96	88-102	86	92-104	88
6000	115	103-124	122	105-133	105	103-109	114	107-124	98	92-122	98
6500	132	118-143	145	123-160	123	120-131	133	126-141	116	109-122	122
7000	151	142-166	164	147-181	144	138-153	156	152-164	133	127-141	143
7500	170	157-180	188	172-205	164	152-175	179	176-182	153	147-162	164
7800	186	177-202	-	-	180	174-190	-	-	-	-	-
8000	-	-	213	200-227	-	-	204	196-211	174	166-188	183
8200	-	-	-	-	-	-	-	-	185	173-202	187

REFERENCES

No.	Author	Title
1	Evans, H.W., Furby, B.E. and Hards, D.J.	"Mini-RPV Programme at WRE". Unpublished Document, June 1976
2	Rockliff, R.J.	"Remotely Piloted Vehicle Technology Task DST 77/033 General Considerations and Current Status July 1978". WSRL-0040-RE, September 1978
3	FE Group	"RPV Aircraft XM-1A Specification (General) Specification FE 102". June 1976
4	Evans, H.W., Landreth, J. and Weeks, F.	"The WSRL XM-1A Mini-Remotely Piloted Vehicle - Airframe Layout, Construction, Ground Tests and Physical Measurements". WSRL-0128-TM, November 1979
5	Burger, F.G.	"The Estimated Sea Level Performance of the DRCS Mini-Remotely Piloted Vehicle (XM-1A)". WSRL-0159-TM, April 1980
6	Kolbo Korp	"Operating Instructions and Service Manual D238. Alcohol - Nitro Methane - Castor Oil Fuel".
7	Hards, D.J., Harman, J.P. and Sentschuck, O.	"The Capacitor Discharge Ignition System for the XM-1A Mini Remotely piloted Vehicle". Unpublished document 1982
8	Catchpole, B.G.	"Propulsion Systems for Australian Remotely Piloted Vehicles". ARL Tech Memo ME 366
9	Pescod, D.	"Design and Development of a 3 1/2 HP Two Cylinder Two Stroke Model Aircraft Engine". ARL Report E67

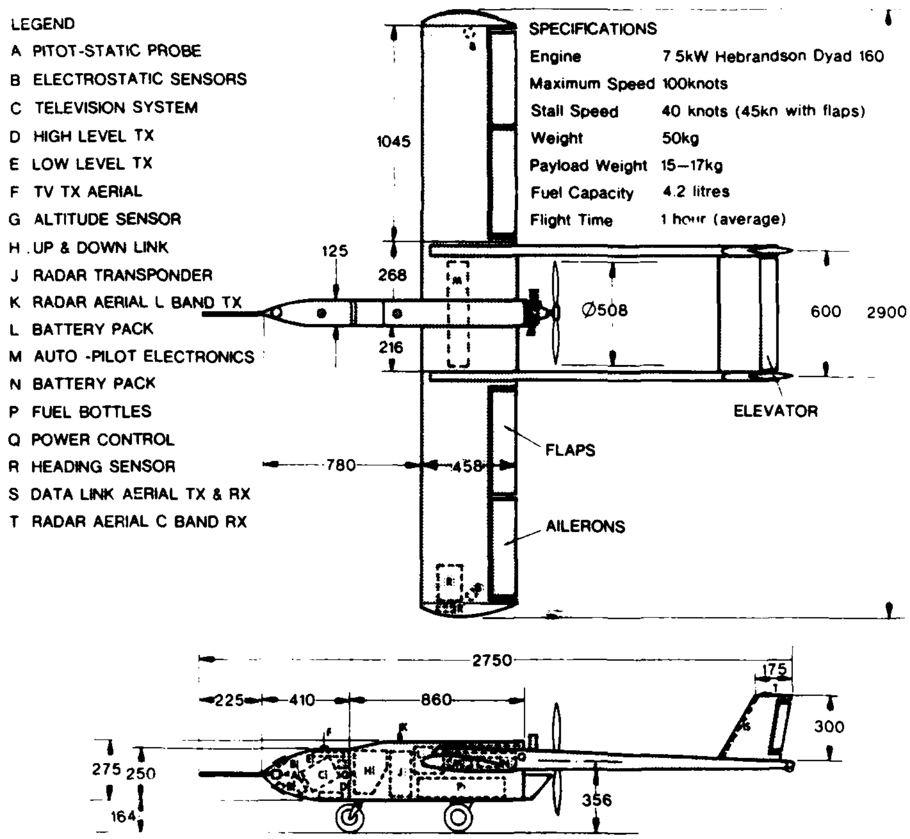

Figure 1. General layout RPV XM-1A (HL17993)

Figure 2. McCulloch MC91, Ross Six and Kolbo D238 2-stroke engines (N77/1730)

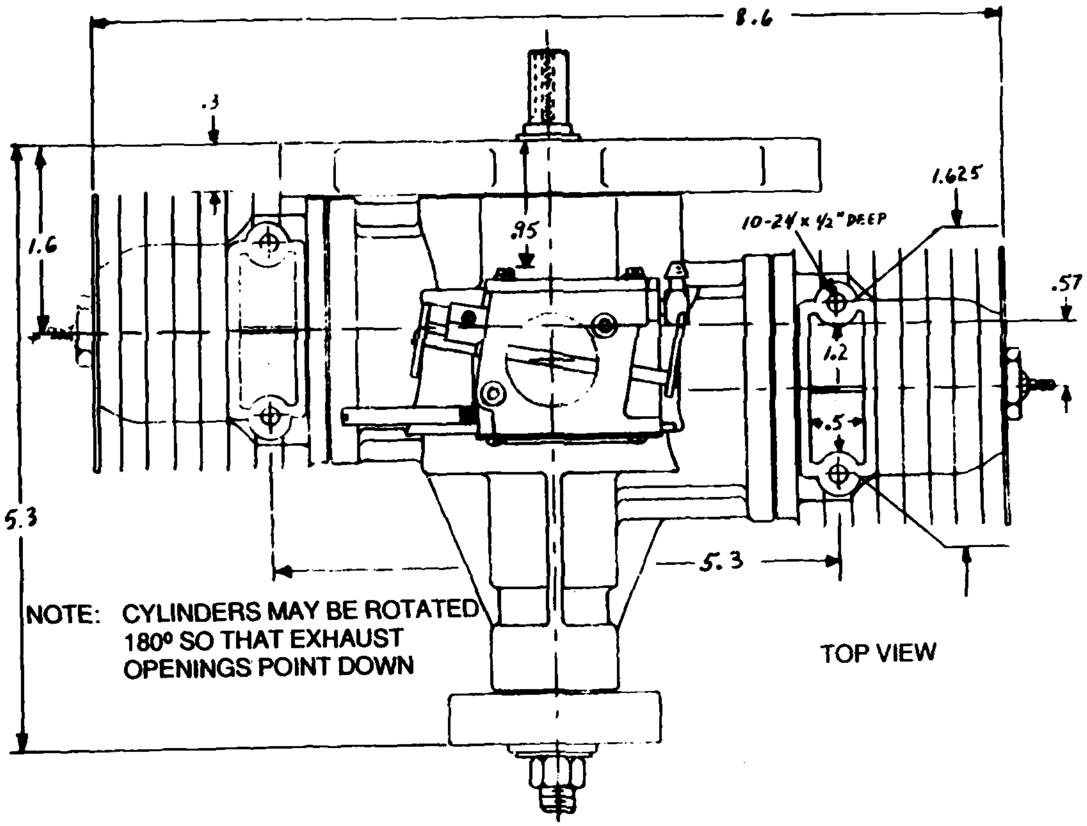

Figure 3. Kolbo D238 engine - top view

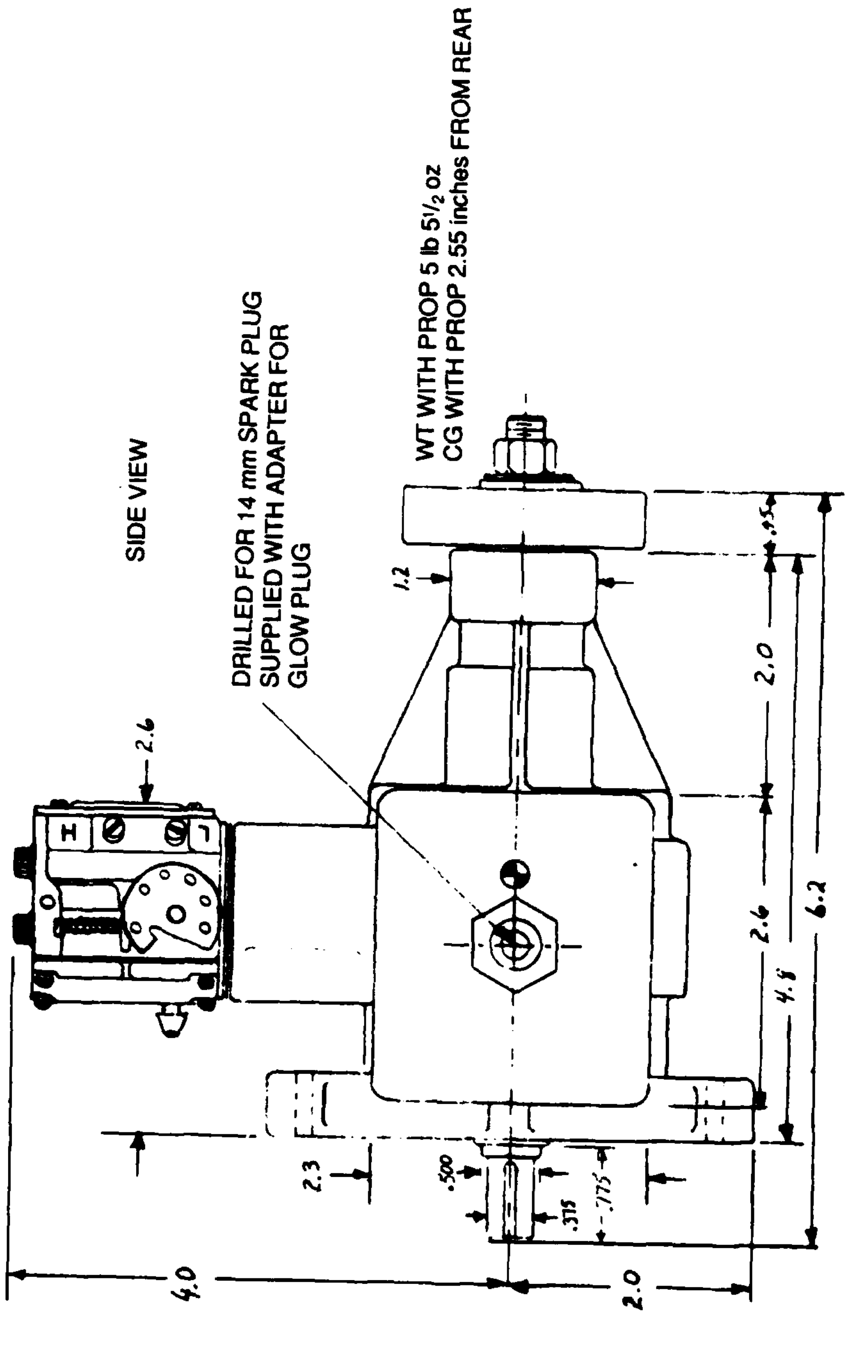

Figure 4. Kolbo D238 engine - side view

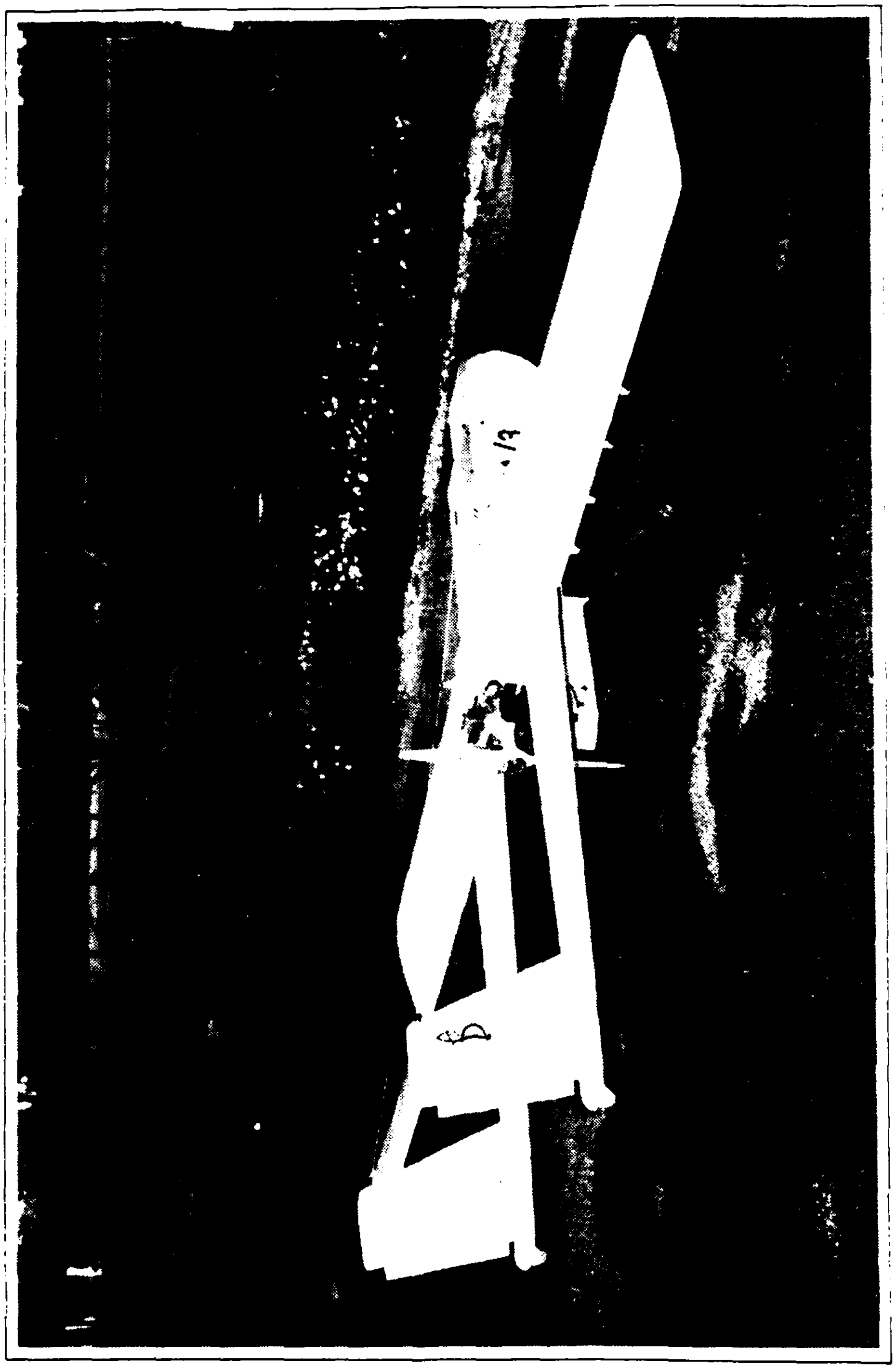

Figure 5. Kolbo D238 engine with CDI fitted to XM-1A aircraft (N78/990)

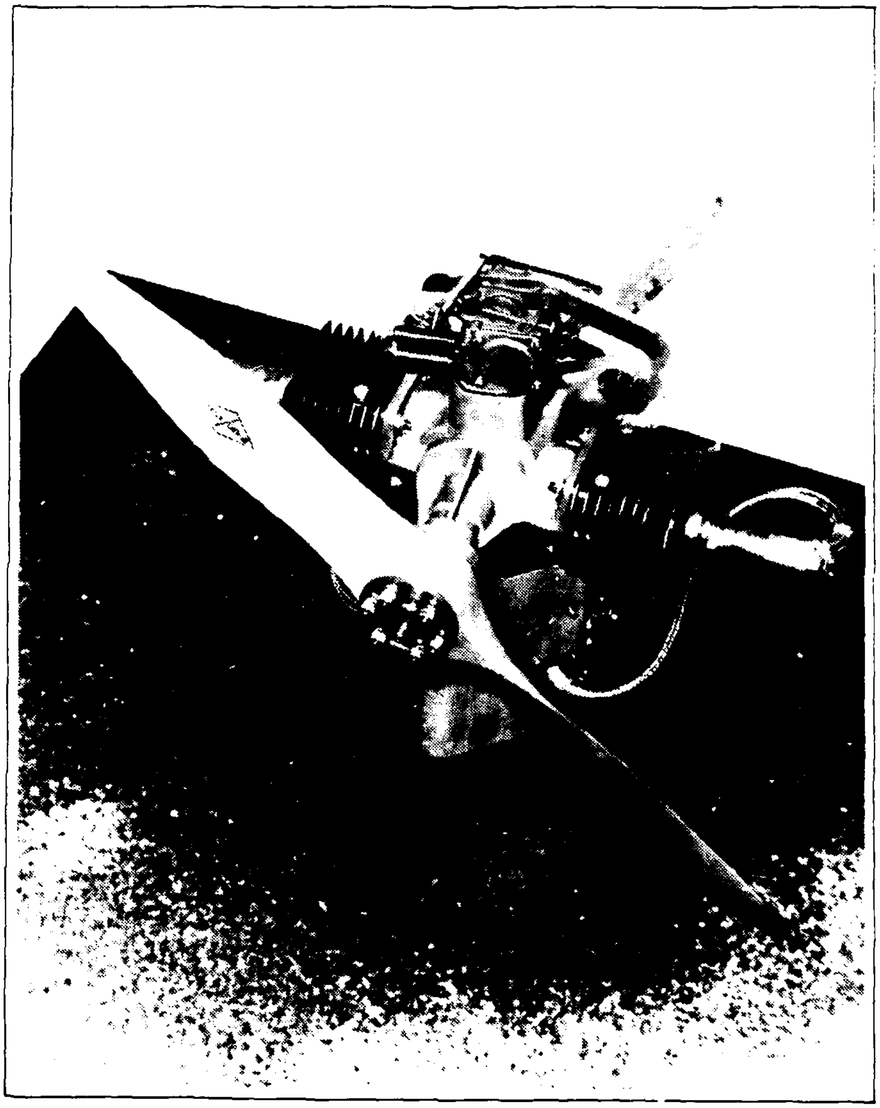

Figure 6. Close up of Kolbo engine with CDI fitted to XM-1A/3 (N75/2285)

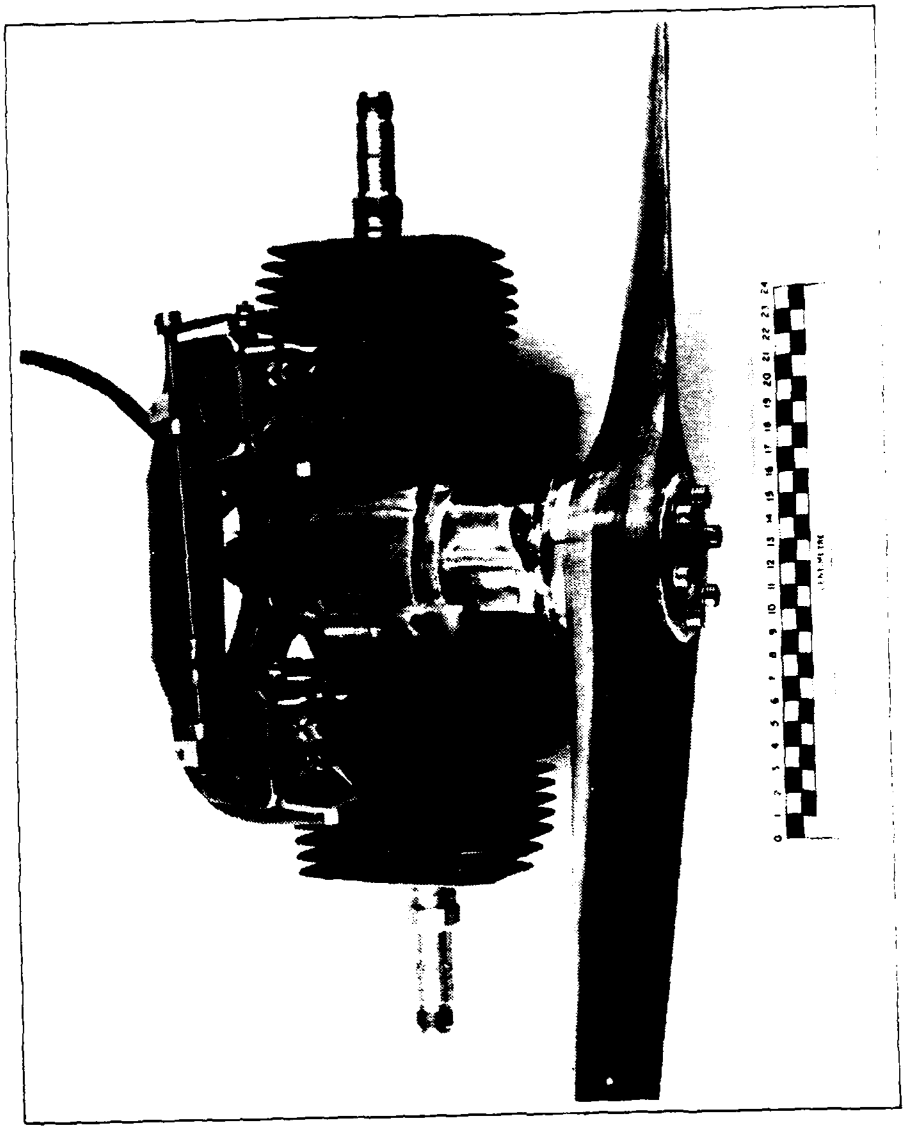

Figure 7. Dyad 160 engine - top view (N82/671)

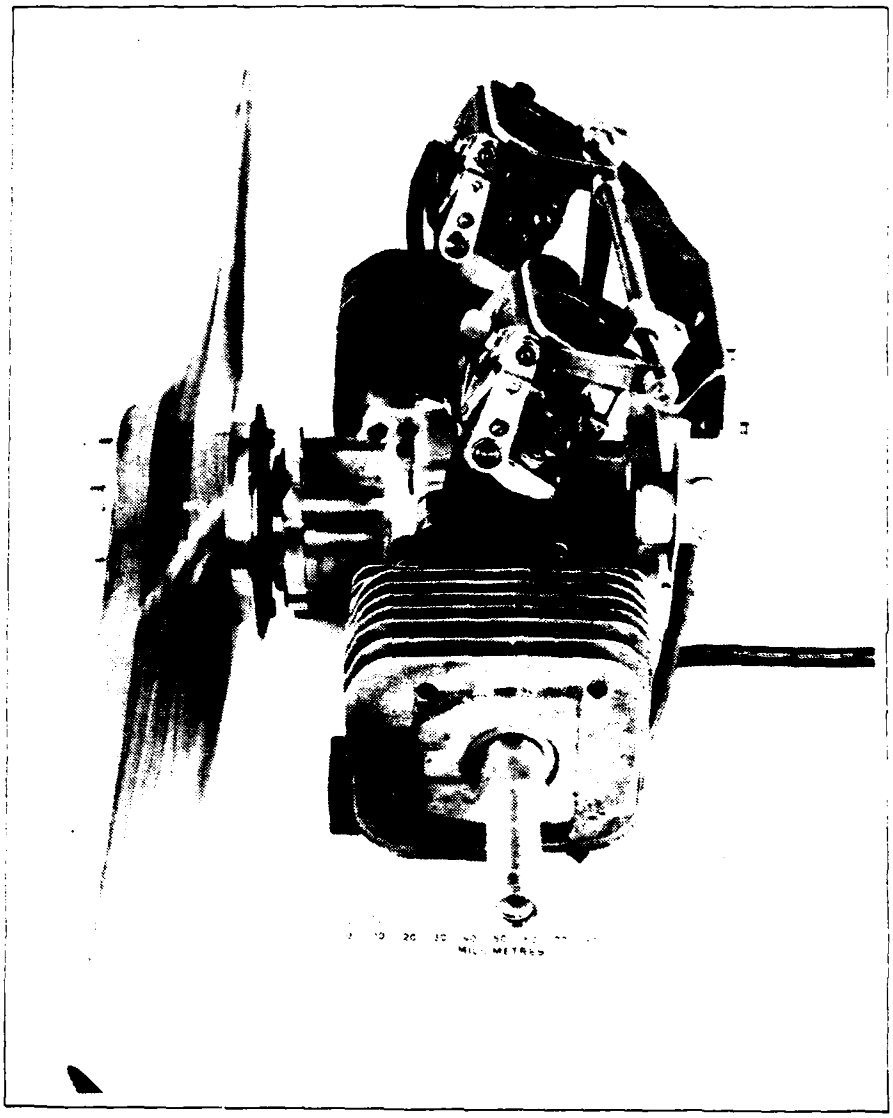

Figure 8. Dyad 160 engine - side view (N82/669)

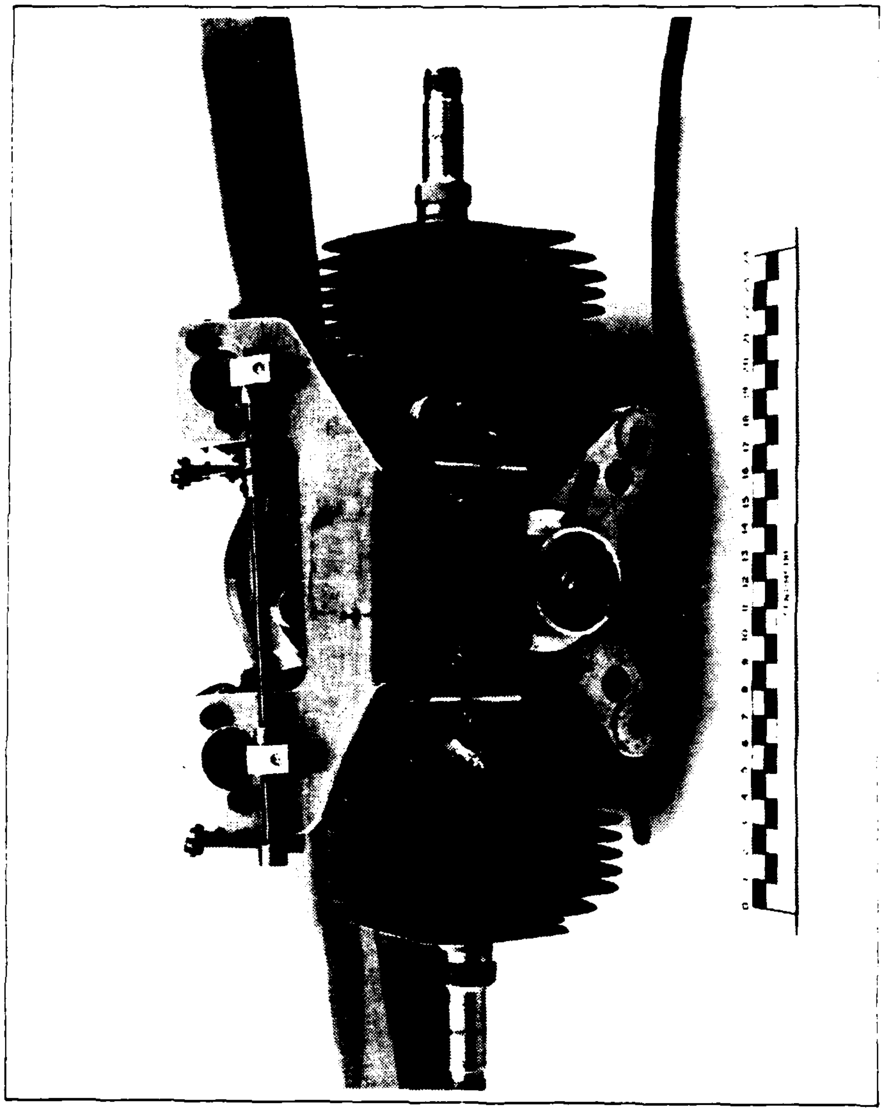

Figure 9. Dyad 160 engine - rear view (N82/667)

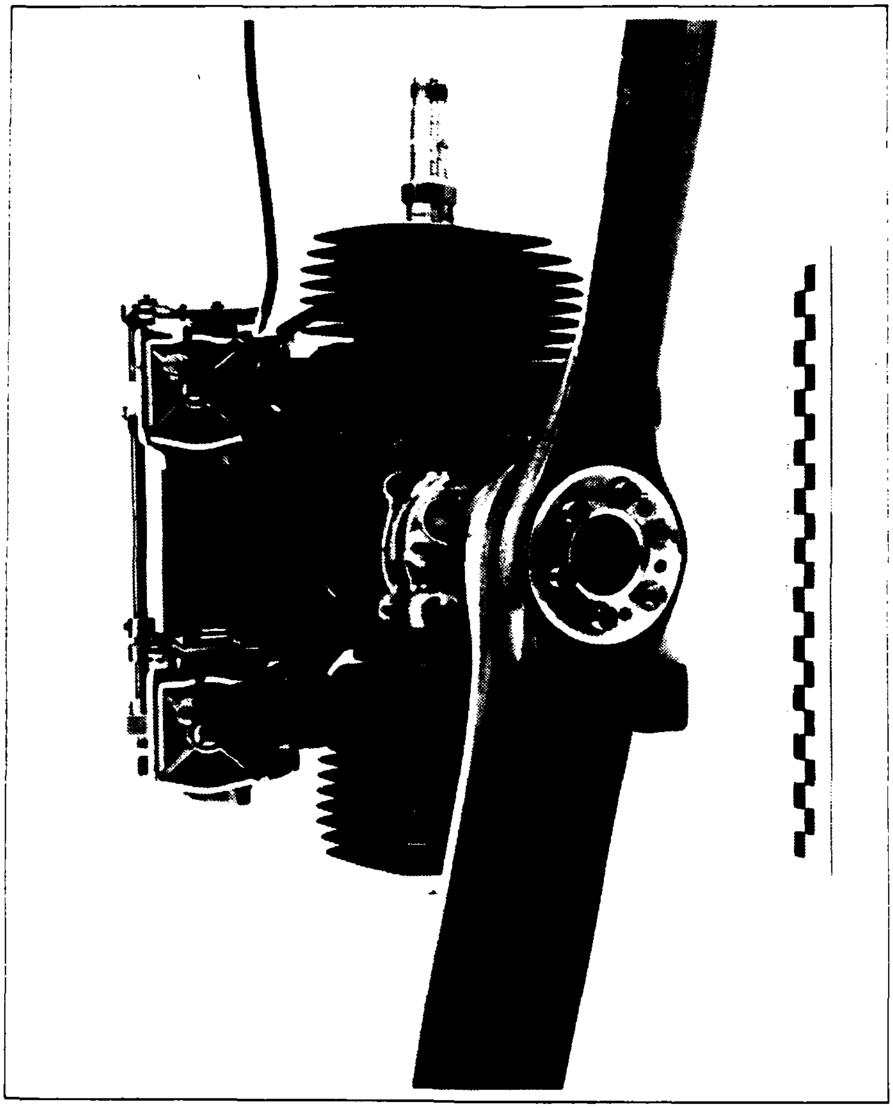

Figure 10. Dyad 160 engine - front view (N82/670)

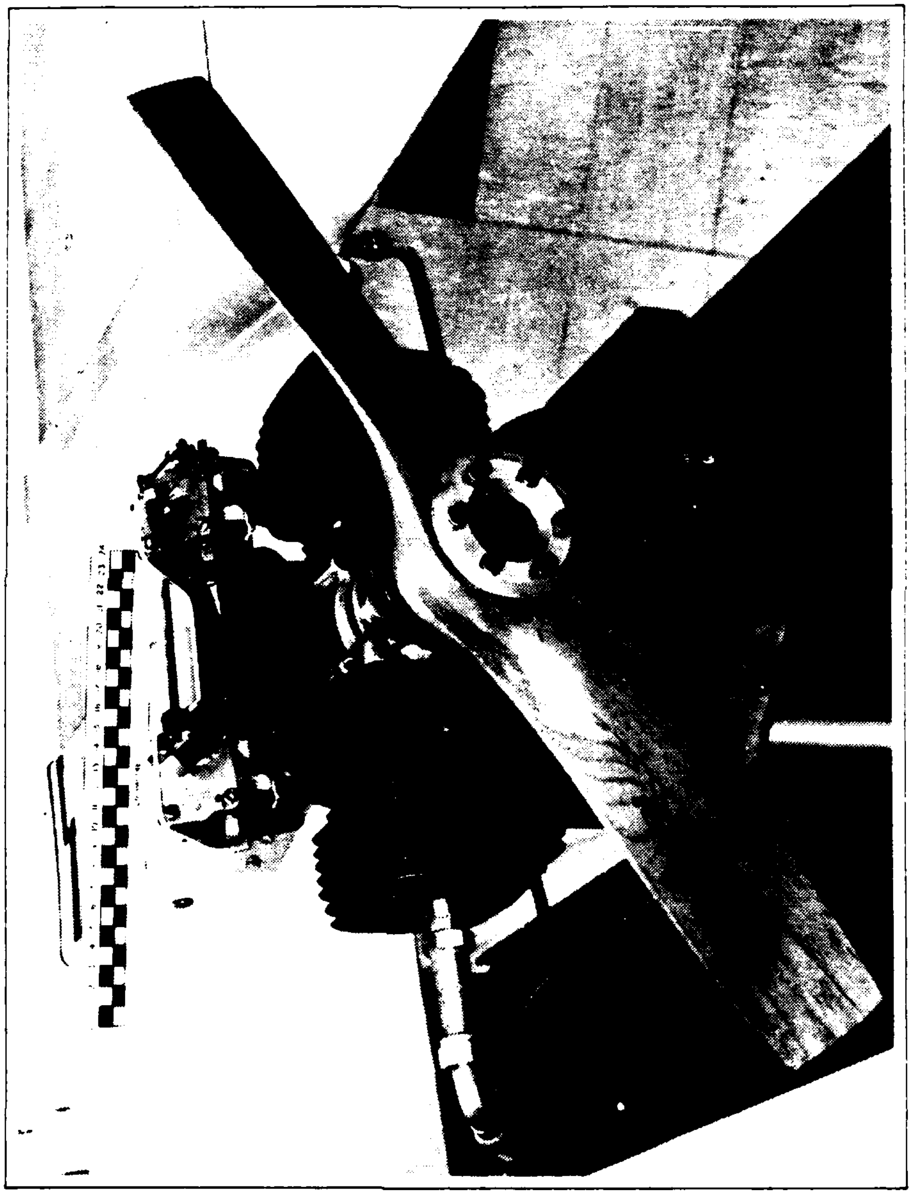

Figure 11. Close up of Dyad engine fitted to XM-1A aircraft (N82/668)

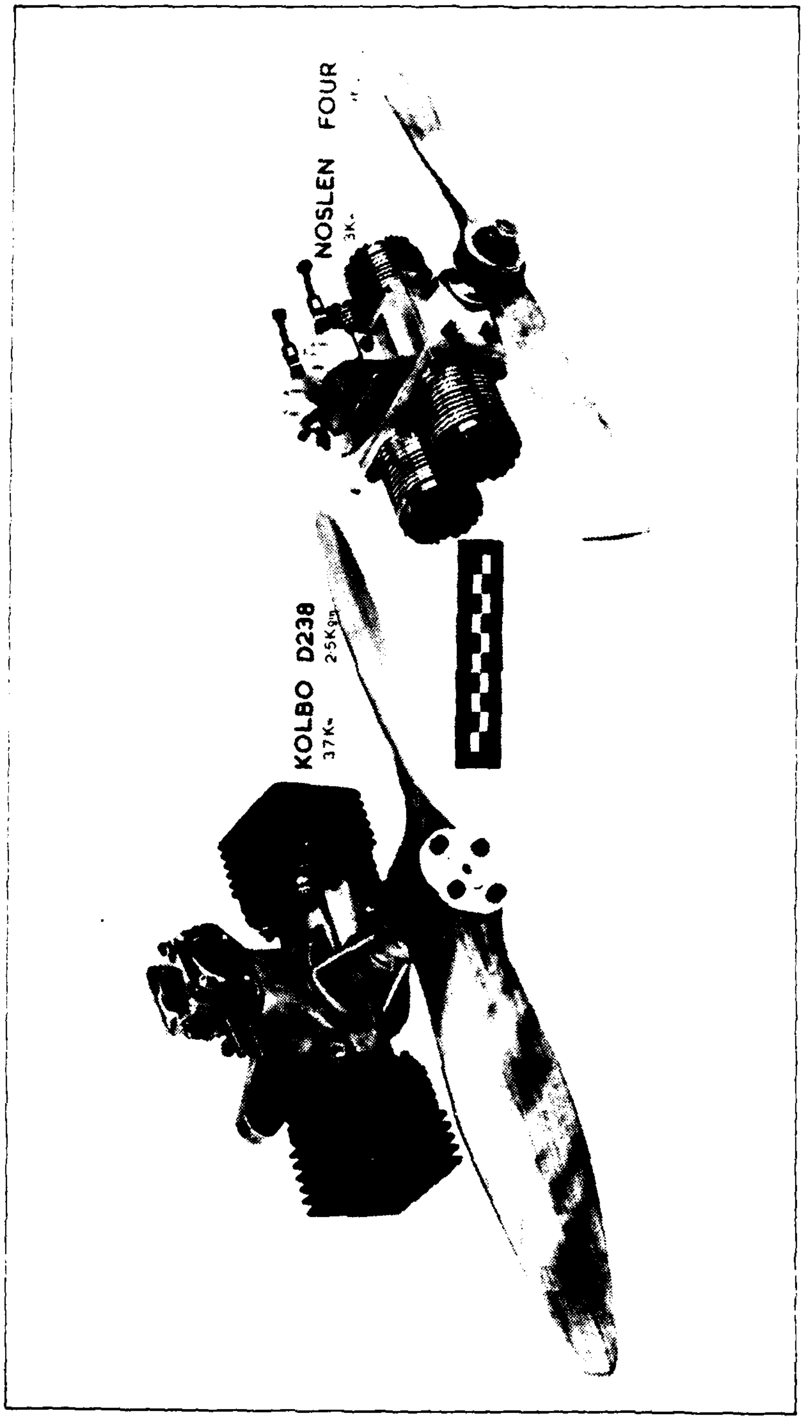

Figure 12. Noslen four and Kolbo D238 engines (N77/1725)

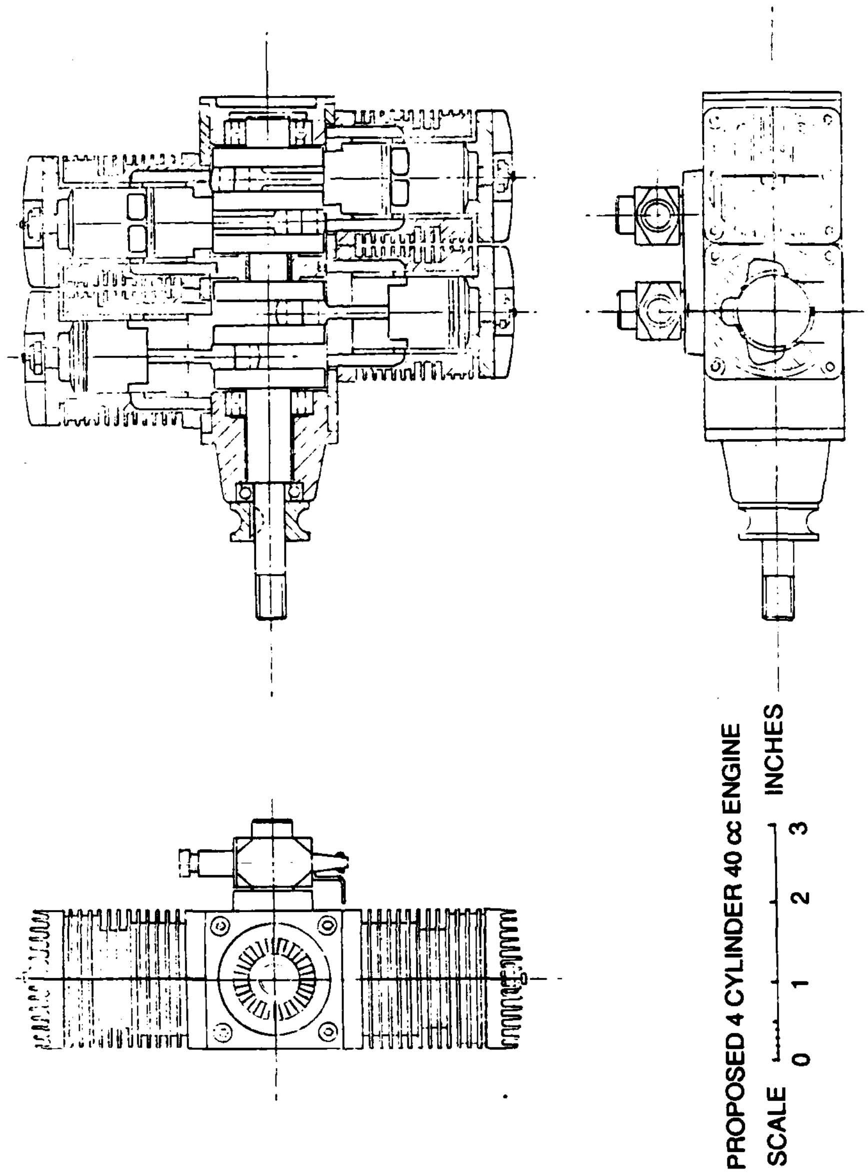

Figure 13. Noslen four cylinder 4 stroke engine

THIS IS A BLANK PAGE

APPENDIX I

NORTHFIELD-ROSSPOWER SIX ENGINE SPECIFICATION

Engine type	:	Six cylinder, 2-stroke cycle, simultaneous opposed pair firing every 120° of rotation, air cooled
Bore	:	20.32 mm (0.800 inches)
Stroke	:	15.24 mm (0.600 inches)
Displacement	:	29.65 cc (1.80 inches^3)
Horsepower	:	3 kW (4 BHP)
Mass	:	1.13 kg (2.5 lb)
Bearings	:	5 ball bearings on shaft, split big-end journals on connecting rods
Carburettor	:	All-attitude Perry (three)
Intake	:	Reed valve induction
Ignition	:	Glow plug
Fuel consumption	:	Approx 0.3 L/HP/h using alcohol nitro-methane fuel for glow plugs
Rotation	:	Either clockwise or counter-clockwise
Length	:	140 mm (5 1/2 inches)
Width	:	127 mm (5 inches)
Height	:	38 mm (1 1/2 inches) less carburetors

See figure 2

APPENDIX II

ENGINE TEST RIG

II.1 Introduction

An mobile engine test rig was developed to allow small engines to be tuned, run in and tested. This rig, shown in figures II.1, II.2 and II.3, provided for the measurement of engine power, thrust and fuel consumption. It was made mobile so that the engine would be mounted on the rig and prepared for an engine run before the rig was moved outside the building for the run.

II.2 Description

The backplate for the engine is attached to a horizontal shaft fixed by bearings to a small platform which is connected by a double parallelogram arrangement to the lower deck of the rig. The platform is constrained in its movement in the direction of the thrust axis of the engine by a vertical bar fastened to the lower deck of the rig. This bar is fitted with strain gauges to measure the thrust of the engine. The strain gauge output can be calibrated by applying known loads and recording the output. The horizontal shaft has a horizontal cross arm from with a pannier hanging from the appropriate outboard end 203 mm (8 inch) from the axis. Masses are placed in the pannier to balance the torque from the engine. The torque is given by the mass times the moment arm.

The rig carries the fuel bottle, ignition system, strain gauge measuring system and rev counter and has a guard to protect personnel from the propeller.

II.3 Installation procedure

II.3.1 Fit engine with propeller as required for test measurements to rig.

II.3.2 Connect throttle linkage.

II.3.3 Fit appropriate fuel bottle to rig. Mixture 24 parts standard petrol/1 part super 2 stroke oil for Dyad engines, and 85% methanol, 5% nitromethane, 10% caster oil mixture for Kolbo engines.

II.3.4 Connect ignition leads from rig mounted CDI to spark plugs.

II.3.5 Connect 240 V supply for strain gauge input.

II.3.6 Check strain gauge output on 0 to 20 mV range.

II.3.7 Connect 240 V supply for RPM counter.

II.4 Safety requirements

II.4.1 All personnel must wear approved type ear muffs.

II.4.2 Check propeller for damage and tightness before start of run.

II.4.3 Remove spare fuel to approved storage area.

II.5 Tuning and running-in

To be carried out to manufacturer's specification.

II.6 Measurement of output power

(To be done in zero or steady light wind conditions)

II.6.1 Fit weight pannier to torque arm.

II.6.2 Run engine until sufficiently warmed up for smooth running.

II.6.3 Unclamp torque arm.

II.6.4 With engine running at lowest stabilised revolution per minute, add masses to pannier until torque arm is balanced. Record mass (including pannier), revolutions per minute, ambient pressure and temperature.

II.6.5 Repeat II.5.4 with engine revolutions per minute increased in incremental steps of 500 rev/min until maximum revolution per minute is attained.

II.6.6 Repeat II.5.4 but with engine revolution per minute decreased in steps of 500 rev/min until initial test revolutions per minute repeated.

II.6.7 Calculate torque for each test condition.

II.6.8 Calculate power for each test condition.

$$\text{Power} = \frac{2\pi \;\; T \;\; R}{12 \times 33\ 000}\ \text{kW}$$

or

$$= \frac{2\pi\ T\ R}{44\ 740}\ \text{HP}$$

where T is measured torque (N m) obtained by multiplying the mass by the torque arm of 0.203 m.

and R is revolutions per minute.

II.7 Measurement of thrust

(To be done in zero or steady light wind conditions)

II.7.1 Ensure that the strain gauged thrust balance is free to move.

II.7.2 Ensure pulley for the "thrust" pannier is clean and free to rotate.

II.7.3 Calibrate strain gauge by applying masses to pannier and recording in voltmeter readings for increasing and then decreasing mass increments.

II.7.4 Run engine until sufficiently warmed up for smooth running.

II.7.5 With engine running at lowest stabilised revolutions per minute record mass, voltmeter reading, ambient pressure and temperature.

II.7.6 Repeat II.7.5 with engine revolutions per minute increased in incremental steps of 500 rev/min until maximum revolution per minute is attained.

II.7.7 Repeat II.7.5 but with engine revolutions per minute decreased in steps of 500 rev/min until initial test revolutions per minute repeated.

II.7.8 Derive thrust developed for each test condition from calibration II.7.3.

II.8 Measurement of engine fuel flow

II.8.1 Measure fuel volume before commencement of run.

II.8.2 Record running time.

II.8.3 Measure fuel volume remaining at end of run.

II.8.4 Calculate flow rate.

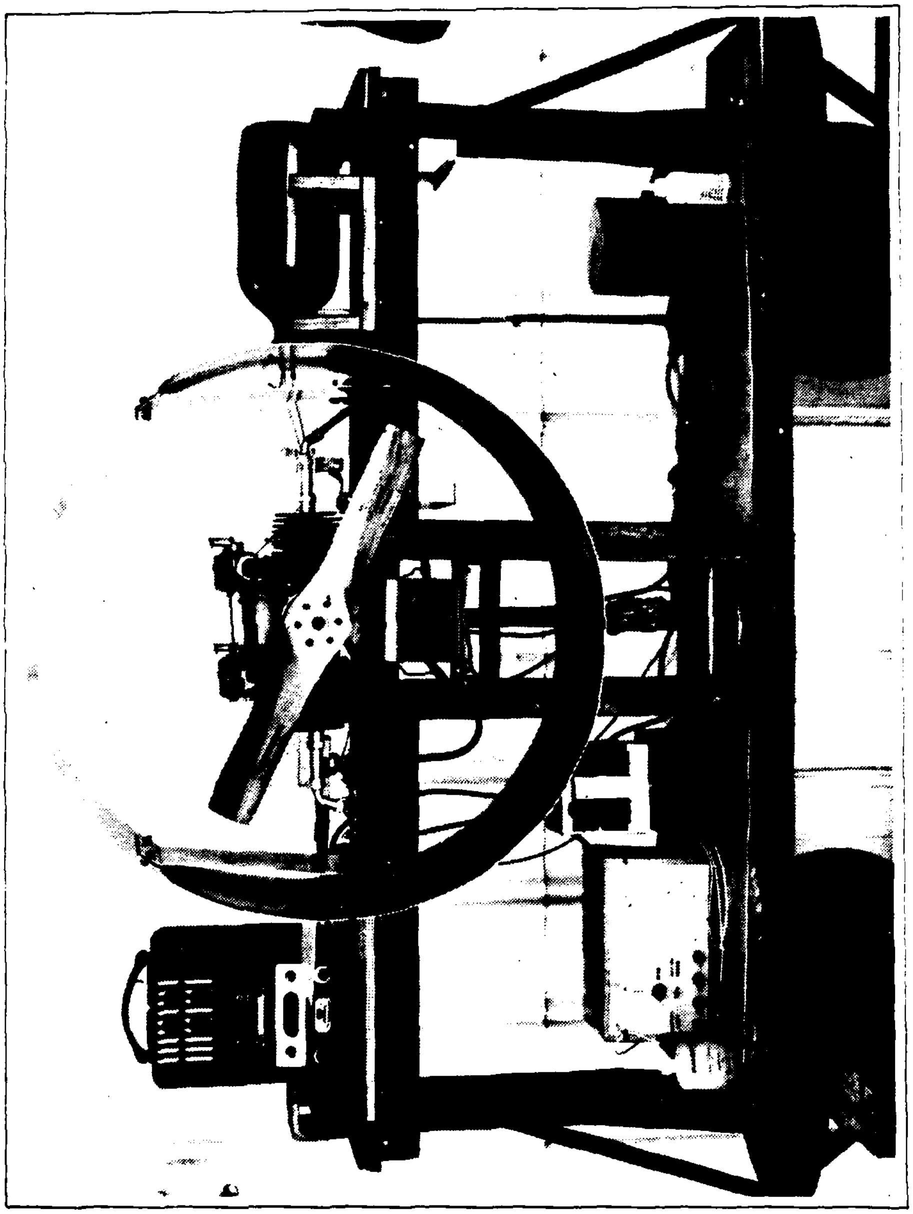

Figure II.1 Engine test rig (N79/1746)

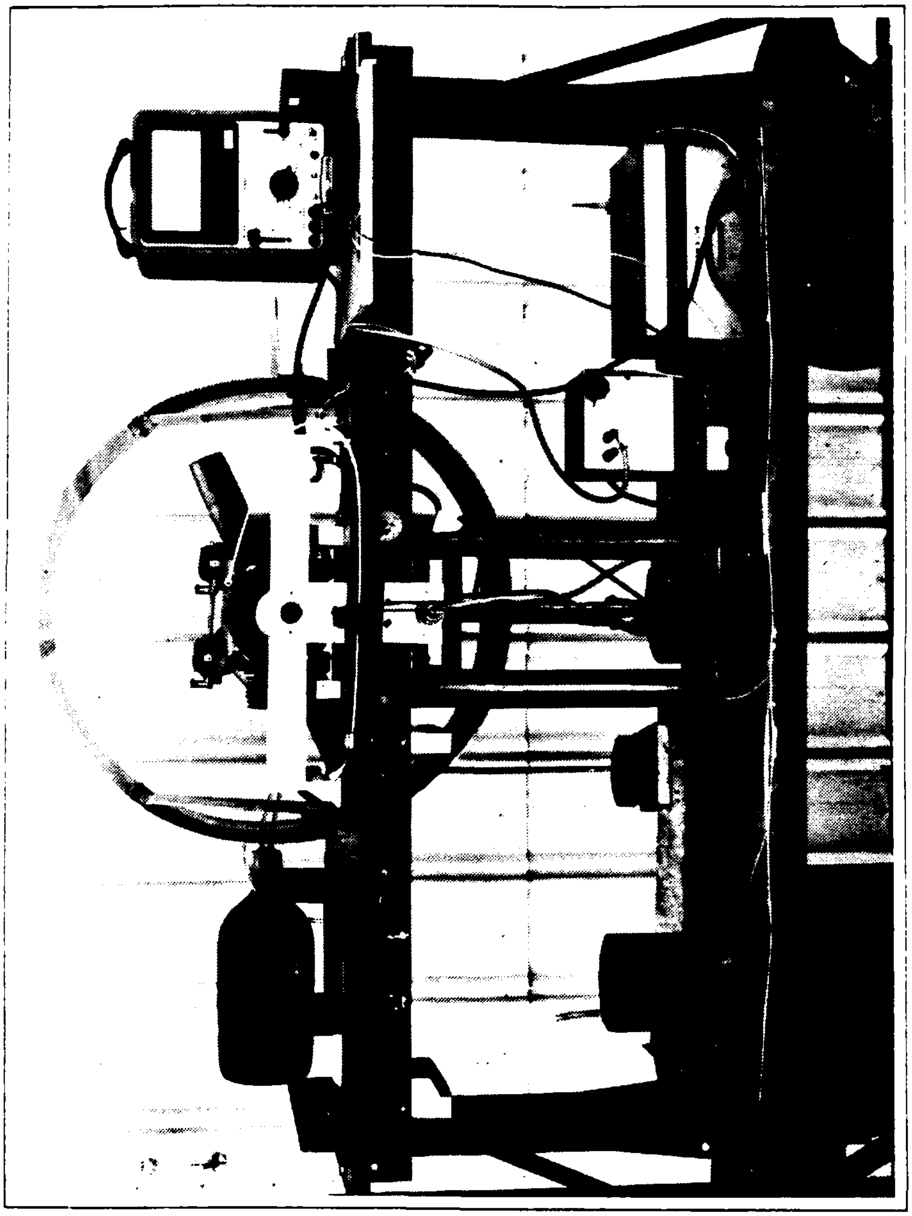

Figure II.2 Engine test rig (N79/1747)

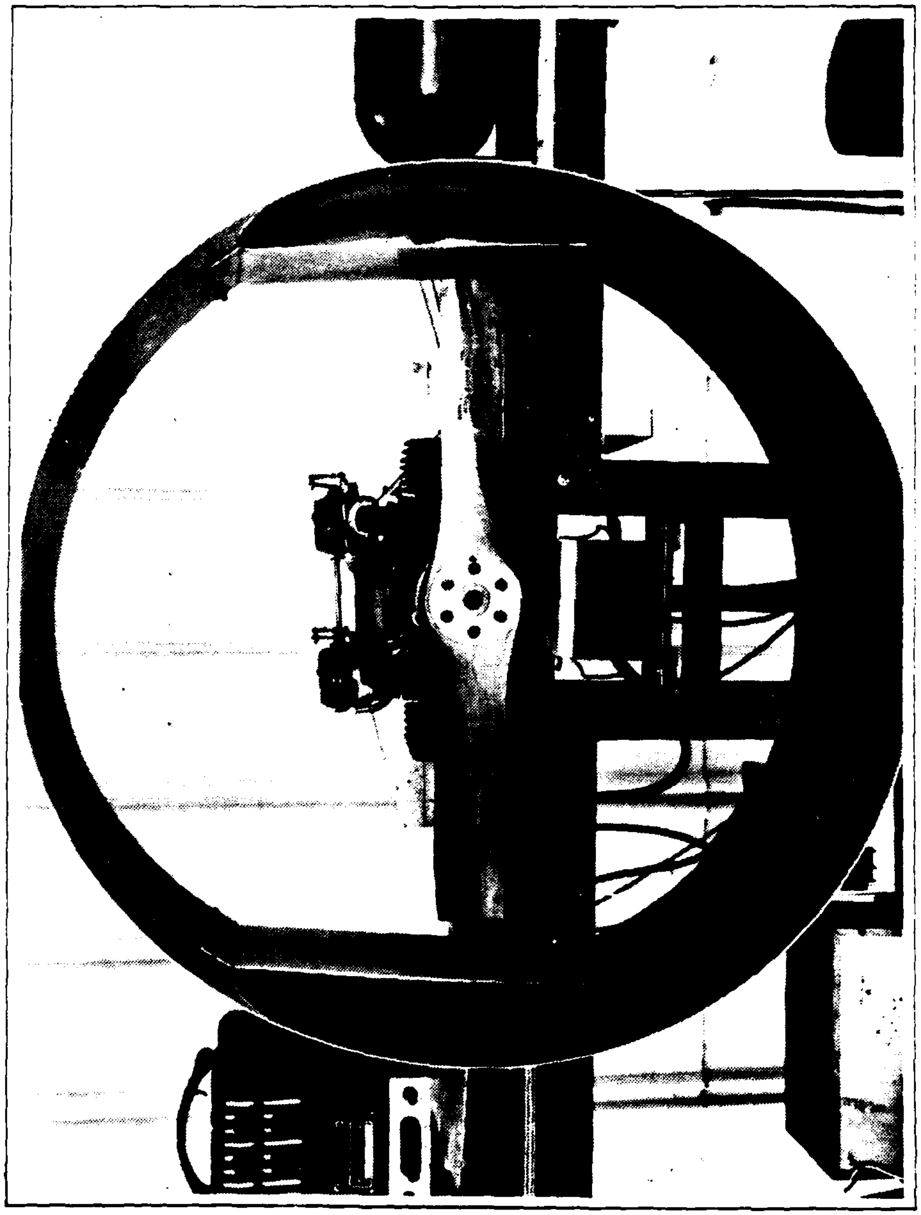

Figure II.3 Close up of engine in test rig (N79/1748)

APPENDIX III

KOLBO D238 ENGINE SPECIFICATION

Engine type	:	Twin cylinder, 2-stroke cycle, opposed, simultaneous firing, air cooled
Bore	:	34.93 mm (1.38 inches)
Stroke	:	32.54 mm (1.28 inches)
Displacement	:	62.28 cc (3.8 inches^3)
Horsepower	:	3.7 kW (5 BHP)
Mass	:	2.10 kg (4.63 lb)
Bearings	:	All roller and needle bearings including front and rear roller thrust bearings
Carburettor	:	Diaphragm type, all attitude Tillotson
Intake	:	High performance, pyramid reed
Fuel consumption	:	approx 0.8 L/HP/h using alcohol nitro-methane fuel for glow plugs
Cooling requirements	:	45 CFM/cylinder minimum at wide open throttle
Rotation	:	Either clockwise or counter-clockwise
Length	:	157 mm (6.2 inches)
Width	:	218 mm (8.6 inches) excluding glow plugs or spark plugs
Height	:	152 mm (6.0 inches) including carburetor

See figures 2, 3, 4, 5 and 6.

APPENDIX IV

KOLBO D238 ENGINES - RUNNING HISTORIES

IV.1 First Kolbo engine, no serial number

22/10/75 First Kolbo engine received and run for 5 min.

24/10/75 Engine run for 10 min.

27/10/75 Kolbo advised us by telephone that the small end bearings required re-aligning. Whilst the engine was dismantled the opportunity was taken to check other items, and the cylinders were found to be out of alignment.

13/11/75 Carburettor adjusted and engine run for 20 min.

17/11/75 Engine with 523 x 457 mm (21 x 18 inches) propeller fitted to XM-1 fuselage and run for 5½, 2½ and 7½ min for engine/airframe checks including measurement of vibration levels. Revolutions per minute min 2000, max 6000.

Maximum vibration levels at 6000 rev/min

Boom lateral		13 g at 500 Hz
Wing tip vertical		11 g at 500 Hz
Centre body vertical		15 g at 1 kHz
Payload section	vertical	6 g at 500 Hz
	lateral	12 g at 250 Hz
Nose vertical		13 g at 250 Hz

No sharp resonant conditions were observed.

19/11/75 Engine run for 20 min in XM-1 fuselage.

06/02/76 Engine with 508 x 457 mm (20 x 18 inches) propeller run for 20 min during an acceleration test at Edinburgh. Problem in getting engine to run in correct direction. Tests abandoned due to intermittent electrical fault in aileron system.

17/02/76 Engine run for 43 min during 8 acceleration and lift off tests with an average fuel consumption of 2.7 L/h. Min revolutions per minute 2000, max 6000. Aircraft at 29.6 kg responded readily to rapid increase in revolutions per minute. Predicted rotation velocity achieved in 30 to 40 m.

20/02/76 Engine run for 20 min during 4 acceleration and lift off tests and initial flight of 1 min. Engine stopped in flight and aircraft damaged on hard landing. Ends ripped off propeller. Suspected that engine stopped due to fuel pressure dropping when fuel system half empty.

09/03/76 Engine run for 7 min and 2 min for fuel tank tests.

10/03/76 Engine run for 10½ min for further fuel tank tests when the propeller driver nut worked loose allowing the propeller to hit the revolution counter arm. The four cap screws securing the propeller to the driver boss were sheared off and the keyway in the crankshaft was fractured.

11/03/76 Engine dismantled.

12/03/76 Replacement crankshaft ordered from Aeroballistics Engineering Section (AES), now Weapon Experiments Group, workshops.

16/03/76 Pistons and cylinders used on engine no 0015.

27/08/76 Modified built-up crankshaft (3 piece press-fitted) received and fitted. New cap screws fitted to connecting rod ends and assembled with 'Loctite'. New locally made pistons (Kolbo copies) and rings lapped into cylinders and fitted.

Engine test run for 40 min on thrust rig.

Ambient temperature: 11°C
Propeller: Kolbo 508 x 457 mm

(rev/min)	Thrust - N	
	run 1	run 2
2000	16	16
3000	32	31
4000	61	58
5000	89	85
6000	122	122

Engine run at varying speeds for 40 min. On attempting to re-start the engine for a further run, the pistons were observed to be out of phase. On dismantling the engine, the crankshaft centre web was found to be distorted out of position, and the shaft was discarded.

03/09/76 Original repaired Kolbo crankshaft re-fitted with a new key and new propeller driver. Engine re-assembled.

09/09/76 Engine test run for 30 min.

Ambient temperature: 10°C
Propeller: Kolbo 508 x 457 mm
Wind: 20 kn

(rev/min)	Thrust (N)
6400	111
6200	111
6100	97
6000	86
5700	89
5200	75
4500	58
4400	52
3300	29
3200	24

17/09/76 Engine run for 5 min.

24/09/76 Engine run for 30 min.

29/09/76 Engine run for 40 min.

30/09/76 Engine run for 40 min, fuel pump cleaned.

07/10/76 Engine run for 20 min.

22/20/76 Engine run for 20 min.

08/11/76 Engine run for 90 min.

09/11/76 Engine run for 10 min.

24/11/76 Engine fitted to XM-1A/1 and run for 10 min while telemetry checks were carried out.

03/12/76 Engine could not be started.

14/12/76 Carburettor removed and cleaned, then engine run for 10 min. An attempt was made to re-start engine 1½ h later, but this was unsuccessful. The cylinders were removed and the piston crowns were observed to have collapsed at the centres.

15/12/76 Pistons sent to Metallurgist for inspection and report.

01/02/77 Report received (See Attachment V.1) and locally made pistons and piston pins ordered (figure V.1).

19/05/77 New pistons, pins and rings fitted. Connecting rod small-end bearing alignment checked. New *locally made* crankshaft fitted with redesigned propeller hub (figure IV.2). Aluminium pins in hub sheared at low revolutions per minute when engine reversal took place. Several changes made to the diameter of the pins, but again these proved to be unsatisfactory.

04/07/77 Another redesigned propeller hub was fitted and the engine was installed in XM-1A/W1 being attached to the airframe with four rubber anti-vibration mounts. The engine was run for 30 min whilst checks were carried out on the controls.

07/07/77 Engine started to enable further control checks to be undertaken. After approximately 10 min running the propeller disintegrated. Subsequent examination revealed that the hub had fractured through a roll-pin hole, allowing the pin to move and embed itself partly into the bore of the propeller prior to failure (figure V.3).

13/07/77 Engine run for 9 min to check improved anti-vibration mount and steel propeller hub tapped for the four 'Unbrako' hardened steel propeller retaining bolts.

19/08/77)
26/08/77) Engine run for a total of approximately 1 h fitted with coil, CD and glow plug ignition respectively.

03/11/77 Engine run on glow plug ignition. Maximum revolutions per minute obtained was 5400 with 508 mm x 457 mm (20 x 18 inches) locally made propeller. After approximately 10 min running time, the four 'Unbrako' propeller bolts failed and the spruce propeller shattered inside the safety guard.

07/11/77 New propeller bolts fitted, manufactured from EN25T molybdenum steel. Engine run for 15 min on glow plug ignition.

08/11/77 Engine run for 15 min fitted with CD ignition. Maximum revolutions per minute obtained was 5900 with 508 mm x 457 mm local propeller. Bolts appeared to be satisfactory. Locking wire securing these intact.

16/11/77 Engine fitted to XM-1A/2 on anti-vibration mounting. Aircraft suspended from gantry on bungee rubber cords. Engine run for 10 min during which time one reversal took place at low revolutions per minute. Vibration accelerometers were fitted to airframe and engine was re-started. Engine throttle was adjusted to give 4000 rev/min and within a minute the molybdenum steel propeller bolts failed and the spruce propeller disintegrated. Lock nut on the propeller hub became loose when engine rpm reached a high peak due to no load. Fuel consumed during test was 899.1 mL. Average fuel consumption was 4.9 L/h.
Broken bolts, hub and propeller sent to AEL Foundry Metallurgist for inspection and report.

29/11/77 WRE Foundry Section note produced on 'Investigation of Kolbo Engine Propeller Failure' (see Attachment V.2).

01/02/78 Engine fitted with redesigned propeller boss with six holes (figure V.4).

02/02/78 Engine run for 1 min to check ignition unit, max revolutions per minute 5500. Engine run for 7 min to check CDI timing adjustment, max revolutions per minute 5700. Engine removed and timing set for 25° before TDC and reinstalled. Fuel mixture used 85% Methanol, 5% Nitro methane and 10% oil. Fuel consumption 5.4 L/h.

03/02/78 Engine with electronic spark ignition and Champion J4J spark plugs test run for 32 min during hot weather. Fuel mix 85% Methanol, 5% Nitro methane, 10% Oil.

Time: 9.12 am
Propeller: WSRL 508 x 457 mm

(rev/min)	Thrust (N)
5700	96
5000	74
4500	60
4000	48
3500	36
3000	33

Fuel consumption check between tests 5.3 L/h.

Carburettor tuned.

Time: 3.35 pm
Propeller: Kolbo 508 x 457 mm

(rev/min)	Thrust (N)
6300	118
6100	111
6000	102
5000	67
4500	60
4000	47
3500	38
3000	33

Fuel used on 2nd and 3rd February was 3.24 L in 40 min running giving average fuel consumption of 4.9 L/h.

06/02/78 Plugs cleaned and adjusted to 0.030 inches. Engine test run for fuel consumption test and measurement of thrust on a cool and windy day.

Time: 10.50 am
Propeller: Kolbo 508 x 457 mm

(rev/min)	Thrust (N)	Time to use 270 mL fuel	Consumption (L/h)
4000		6 min 14.5 s	2.6
5000		4 4.5	4.0
6000	113	3 11.5	5.1
5500	89	3 7.0	5.2
4500	56	3 49.5	4.2
6300	109	3 14.0	5.0
6000		2 58.5	5.4
60C0	98	3 1.0	5.4
5000	70	3 43.0	4.4
5000		3 52.5	4.2
5500		3 24.5	4.7
6000		3 46.0	4.3
Average consumption			4.4

Ignition removed for transformer change.

15/02/78 Engine with glow plugs fitted to XM-1A/W1 for taxi trials at AD. After 20 min running engine stopped. When restarted it ran for a few mins then stopped again. Would not restart. Engine dismantled and several broken big end needle rollers found, with one being lodged and crushed into a cylinder port.

Total running time of engine was approximately 15 h including about 2 h with spark plug ignition.

IV.2 Second Kolbo engine, Serial No. 0015.

26/01/76 Engine received.

12/03/76 Carburettor adjusted and engine run for 30 min. Average consumption at full throttle, approx 6000 rev/min, was 6.1 L/h.

15/03/76 Engine fitted to XM-1.

16/03/76 Taken to Edinburgh for flight trials. Pilot requested that mixture be weakened for slow running jet. Engine failed to give maximum revolutions per minute in flight and eventually stopped after flight time of 4 min on flight No. 2 of XM-1. Engine running time 20 min.
Engine removed from XM-1 and fitted to test rig without alteration to carburettion. Engine run at varying revolutions per minute but with maximum of only 4800 rev/min for 55 min when a 'plop' was heard from one cylinder when engine was running at 3800 rev/min. Engine was stopped and cylinders were removed and it was noted that the piston crown in the starboard cylinder had collapsed (see Attachment V.3). The pistons and cylinders from first Kolbo were then fitted as the latter was awaiting a new crankshaft.

18/03/76 Carburettor re-set and engine run for 30 min. Average fuel consumption at 6000 rev/min with 508 x 457 mm propeller was 5.9 L/h.

19/03/76 Engine run for approximately 20 min. Fuel consumption with 508 x 457 mm propeller at 6000 rev/min was 5.4 L/h. Average fuel consumption when fitted with small propeller 378 x 457 mm (14 7/8 x 18 inches) at 8000 rev/min was 7.2 L/h.
Engine fitted to XM-1A/3 fuselage.

25/03/76 XM-1 flown, flight No. 3 from Edinburgh for 9 min. Fuel consumed 3 L.
Aircraft refuelled and flown again on flight No. 4, but it crashed after about 4 min flight time due to a boom structural failure. Engine crankshaft suffered damage at propeller end of crankshaft. Crankshaft was removed and sent to the workshop for repair.

Engine running time was 35 min.

08/06/76 Engine reassembled with repaired Kolbo crankshaft and run for 20 min on test rig, thrust 34 N, average torque 55 Nm, power 4 kW (5.3 HP).

28/06/76 Engine run for 30 min to check test rig.

29/06/76 Engine test run for 20 min in test rig to check propellers.

Time: 1130 am
Ambient temperature: $11^{\circ}C$
Pressure: 1019 HPa

(rev/min)	Thrust N	
	Kolbo 508 x 457 mm	BH 508 x 457 mm
3000	-	36
3500	50	-
4000	75	67
4500	80	82
4750	-	84
5000	90	-
5500	111	-
5800	120	102

11/11/76 Engine test run for 30 min for test rig checks.

20/12/76)Engine run for approximately 1 h at an average ambient
21/12/76)temperature of $38^{\circ}C$.
22/12/76)

(rev/min)	Thrust	Torque	Power		Remarks
	(N)	(N m)	(HP)	(kW)	
6100	111	4.5	3.9	2.9	Kolbo propeller
5800	101	4.3	3.5	2.6	508 mm (20 inches) diameter
5000	73	2.8	2.0	1.5	457 mm (18 inches) pitch*
4500	59	2.4	1.5	1.1	
4000	46	1.8	1.0	0.7	
3500	35	1.5	0.7	0.5	
3000	25	1.1	0.5	0.4	
8400	99	4.1	4.8	3.5	Cut-down Kolbo propeller
8000	89	3.6	4.1	3.0	381 mm (15 inches) diameter
7000	68	2.8	2.8	2.0	457 mm (18 inches) pitch*
6000	47	1.9	1.6	1.2	
6000	83	4.3	3.6	2.7	WSRL propeller
5900	78	3.9	3.3	2.5	508 mm (20 inches) diameter
5700	76	3.9	3.2	2.4	355 mm (14 inches) pitch
5000	56	2.9	2.0	1.5	
4500	44	2.5	1.6	1.2	
4000	35	1.9	1.1	0.8	
3500	29	1.6	0.8	0.6	
3000	22	1.2	0.5	0.4	
5900	98	4.3	3.6	2.7	WSRL propeller
5500	82	3.7	2.9	2.2	483 mm (19 inches) diameter
5000	47	2.5	1.7	1.3	457 mm (18 inches) pitch

*NOTE: 457 mm pitch on Kolbo is approximately equivalent to 343 mm pitch on WSRL propeller.

04/03/77 Engine with 508 x 457 mm propeller run for 47 min and then run for 8 min for vibration test at Central Test House (CTH) AEL.

07/03/77 Engine run for 20 min for taxi trials at AD.

09/03/77 Engine run for 10 min for telemetry checks.

10/03/77 Engine run for 5 min in XM-1A/W1 for vibration tests.

17/03/77 Engine run for 15 min in XM-1A/W1 for vibration tests. In the afternoon, the engine could not be restarted. Inspection revealed the port cylinder piston crown had collapsed. Replacement pistons were manufactured to AES design (see figure IV.1).

29/04/77 New locally made pistons and rings fitted. Piston crowns 0.030 inches thicker than the originals. Carburettor stripped and cleaned and reed valves checked.

04/05/77 Engine test run for a total of 100 min.

Time:	1030 am	1130 am	1230 pm
Ambient temperature:	24°C	25°C	24°C
Pressure:	1015 HPa	1014 HPa	1013 HPa
Propeller:	508 x 457 mm		

Time	Running details	Fuel used (mL)	Consumption (L/h)
0925	run for 10 min at 3800 rev/min run for 10 min at 4000 rev/min	742	2.2
1025	run for 10 min at 4200 rev/min run for 10 min at 4400 rev/min	1080	3.2
1055	run for 10 min at 4600 rev/min run for 10 min at 4800 rev/min	1012	3.0
1120	run for 10 min at 5000 rev/min run for 3 min at 5200 rev/min	945	4.4
1152	run for 10 min at 5400 rev/min run for 10 min at 5600 to 6000 rev/min	1620	4.9

Engine run for a further 7 min to check carburettion and fuel used was 540 mL. Average consumption 4.6 L/h.

New locally made pistons looked good, revolutions per minute steady, and no sign of discolouration.

06/05/77 Engine run for a total of 60 min.

Meteorological data

Time:	0830 am	0930 am	1030 am	1130 am
Ambient temperature:	15.4°C	16.0°C	17.8°C	17.8°C
Pressure:	1016 HPa	1017 HPa	1017 HPa	1017 HPa

Time: 0830 am
Propeller: Kolbo 508 mm x 457 mm

(rev/min)	Torque	Power	
	(N m)	(HP)	(kW)
6000	4.9	4.1	3.0
5500	4.3	3.2	2.4
5000	3.5	2.5	1.9
4500	2.9	1.8	1.3
4000	2.2	1.2	0.9
3500	1.8	0.9	0.7

Average fuel consumption 2.8 L/h.

Time: 1030 am
Propeller: Kolbo 508 mm x 457 mm

	Propeller size (mm)			
	508 x 457 (20 x 18 inches)	419 x 457 (16½ x 18 inches)	356 x 457 (14 x 18 inches)	330 x 457 (13 x 18 inches)
High throttle revolutions per minute	5800	6600	7400	7900
Torque N m	4.3	4.2	4.2	5.8
Power kW (HP)	2.6 (3.5)	3.2 (3.8)	3.2 (4.3)	4.8 (6.4)
Medium throttle revolutions per minute	5100	5600	6400	6900
Torque N m	3.5	3.0	2.5	4.2
Power kW (HP)	1.9 (2.5)	1.8 (2.4)	1.6 (2.2)	3.0 (4.1)
Low throttle revolutions per minute	4000	4500	5200	5300
Torque N m	2.1	1.7	1.7	2.4
Power kW (HP)	0.9 (1.2)	0.8 (1.0)	0.9 (1.2)	1.3 (1.8)
Fuel used - mL	337.5	202.5	168	168
Run - s	360	150	165	105
Average consump L/h	3.4	4.9	3.7	5.8

06/05/77 Time: 2 pm
Continued Ambient temperature 19.5°C

Engine test run to measure cylinder temperatures. The temperature was allowed to stabilise at the same throttle setting for each propeller and the following temperatures were recorded after the engine was run for a further minute.

Propeller size (mm)	(inches)	Throttle	(rev/min)	Cylinder temperature °C
508 x 457	20 x 18	100%	5800	179
		75%	4100	121
419 x 457	16½ x 18	100%	6600	144
		75%	4700	134
		50%	4300	106
355 x 457	14 x 18	100%	7400	140
		75%	6300	134
		50%	5100	119
330 x 457	13 x 18	100%	7800	127

The engine was run for 1 min at the each throttle setting for each propeller and the following temperatures were recorded at the end of another minute of running.

Propeller size (mm)	(inches)	(rev/min)	Cylinder temperature °C
508 x 457	20 x 18	5800	132
419 x 457	16½ x 18	6600	144
355 x 457	14 x 18	7400	140
330 x 457	13 x 18	7800	128

Engine was run at 5000 rev/min for each propeller for 1 min and the following temperatures were recorded at the end of another minute.

Propeller size (mm)	(inches)	(rev/min)	Cylinder temperature °C
508 x 457	20 x 18	5000	118
419 x 457	16½ x 18	5000	122

06/05/77 Continued The following temperatures were recorded after 3 min running at full throttle for each of the four propellers.

Ambient temperature: 20.0°C

Propeller size (mm)	(inches)	Full throttle (rev/min)	Cylinder temperature °C
508 x 457	20 x 18	5900	132
419 x 457	16½ x 18	6400	143
355 x 457	14 x 18	7300	116
330 x 457	13 x 18	7800	126

Fuel used for tests between 1030 and 1410 h was 3¼ L. Average fuel consumption was 3.2 L/h.

11/05/77 Engine run for 15 min in aircraft for control checks.

27/05/77 Engine run for 10 min in aircraft for radio frequency interference (RFI) checks.

21/06/77 Engine run for 10 min in XM-1A/W1 to check vibration levels. Engine mounting bracket observed to be fractured after run. One glow plug failed causing engine reversal.

29/06/77 Engine run for 20 min in XM-1A/W1 to check vibration levels, using a modified engine mount with silicon rubber bushes. Mount did not appreciably reduce vibration in airframe.

01/07/77 Engine run for 5 min attached to test rig with four "Silentblock" anti-vibration mountings. Vibration levels greatly reduced. One mount was soaked in fuel for 2 days, then a tensile load of 35 kg was applied for 2 days without showing any sign of deterioration in the bonding of the rubber to metal surfaces.

22/07/77 Engine run for 12 min to check power output using 2 different fuel mixtures.

Ambient temperature: 10°C
Propeller: WSRL 508 x 457 mm

(rev/min)	Fuel	Thrust (N)	Torque (N m)	Power (HP)	(kW)	Run (s)	Fuel (mL)	Consumption (L/HP/h	L/h)
5500	No 1	103	4.3	3.3	2.5	140	200	1.6	5.3
5500	No 2*	105	4.5	3.4	2.5	136	200	1.6	5.3

	Fuel No. 1	Fuel No. 2*
Methanol	77%	80%
Nitro-Methane	3%	10%
Oil	20%	10%

* Recommended by manufacturer

22/07/77 Measurements are considered unreliable due to gusty conditions.
Continued

03/10/77 Engine run for 12 min to check movement on "Silentblock" mounts.

07/10/77 Engine run for 9 min to check further modifications to mounts.

19/10/77 Engine run for 15 min with CD ignition (unscreened prototype).

20/10/77)
31/10/77)Engine run for 60 min with CD ignition to check
01/11/77)spark plugs.

01/11/77 Engine with glow plug ignition, fitted to XM-1A/W1 for taxi trials. Running time 30 min. Average consumption 3.1 L/h.

16/02/78 Engine run on test rig for carburettor adjustment.

Engine with Kolbo 508 x 457 mm propeller fitted to XM-1A/W1.

17/02/78 Taxi trials at Edinburgh to test arrestor net. Port wing slightly damaged when it hit net support. Engine running time 34 min.

20/02/78 Engine dismantled to check big-end bearings and reassembled. Engine refitted to XM-1A/W1 taxi trials at Edinburgh.

Flight trial 1A/W1 for 1 min with glow plug ignition. Crashed on landing. Engine running time 27 min.

24/02/78 Engine run for 21 min on test rig to check for interference on Kraft controls.

17/03/78 Engine run for 6½ min with light weight CDI. Timing required alteration.

20/03/78 Timing readjusted engine run for 34 min to check use of various spark plugs and coils. Max revolution per minute 5400.

21/03/78 Engine with 508 x 355 mm propeller test run.
Using J4J plugs, max revolution per minute 5300 and fuel consumption 4.09 L/h.
Using miniature plugs, max revolutions per minute 5300. Erratic running at low revs.
Screened CDI, screened leads and J4J plugs fitted. Ran well.

Engine running time 23 min.

03/04/78 Engine run for 10 min for control checks.

18/05/78 Engine fitted to XM-1A/2 and ran for 4 min for carburettor adjustments.
Engine run for 10 min for TV and control interference checks.

13/06/78 Engine run for 25 min for WSD control checks, max revolutions per minute 7100.

03/07/78 Engine run for 75 min for TV and control checks.

11/07/78 Engine run for 20 min, plugs changed from J4J to XE-J6. Did not run well.

Engine run for 5 min with XE-J6 plugs but not satisfactory.

19/07/78 Engine run for 10 min to check TV camera.

21/07/78 Engine run for 58 min for vibration tests on airframe and components.

22/08/78 Engine run for 5 min to complete vibration checks.

Engine was then removed from XM-1A/2.

Total running time of engine, serial number 0015, was approximately 13 h including 1½ h with spark plug ignition.

IV.3 Third Kolbo engine, Serial No. 0031

07/02/77 Propeller mounting bolts were found to be too short and were replaced.

23/02/77 Engine test run for 17 min.

Time:	11.30 am	12.30 pm
Ambient temperature:	26.3°C	27.5°C
Pressure:	1006.7 HPa at 12 noon	
Propeller:	Kolbo 508 mm x 457 mm	

Throttle	(rev/min)	Thrust (N)	Torque (N m)	Power		Run time	Fuel used	Consumption	
				(HP)	(kW)	(s)	(mL)	(L/HP/h	L/h)
100%	6000	114	4.5	3.8	2.8	138	255	1.8	6.7
75%	5000	77	3.1	2.2	1.6	226	255	1.8	4.1
50%	4000	52	2.1	1.2	0.9	660	255	1.2	1.4

24/02/77 Engine test run for 15 min.

Time:	11.30 am	12.30 pm
Ambient temperature:	22.2°C	21.7°C
Propeller:	WSRL 419 mm x 457 mm (16.5 x 18 inches)	

Throttle	(rev/min)	Thrust (N)	Torque (N m)	Power		Run time	Fuel used	Consumption	
				(HP)	(kW)	(s)	(mL)	(L/HP/h	L/h)
100%	6800	101	4.3	4.2	3.0	126	270	1.9	7.7
75%	5500	67	2.9	2.2	1.6	246	270	1.8	4.0
50%	4500	44	2.1	1.3	1.0	480	270	1.6	2.0

Engine test run for 15 min.

Time: 10.45 am
Ambient temperature: 21°C
Pressure: 1010 HPa
Propeller: WSRL 324 mm x 457 mm (12.75 x 18 inches)

Throttle	(rev/min)	Torque (N m)	Power		Run time	Fuel used	Consumption	
			(HP)	(kW)	(s)	(mL)	(L/HP/h	L/h)
100%	8600	2.9	3.5	2.6	109	270	2.6	8.9
75%	7000	2.1	1.9	1.4	124	270	4.0	7.8
50%	5600	1.4	1.1	0.8	647	270	1.3	1.5

25/02/77 Engine test run.

Time: 1.45 pm
Ambient temperature: 22°C
Pressure: 1009.8 HPa
Propeller: WSRL 356 mm x 457 mm (14 x 18 inches)

Throttle	(rev/min)	Torque (N m)	Power		Run time	Fuel used	Consumption	
			(HP)	(kW)	(s)	(mL)	(L/HP/h	L/h)
100%	7700	3.5	3.7	2.7	115	270	2.27	8.4
75%	6300	2.3	2.0	1.5	163	270	2.98	6.0
50%	5000	1.6	1.2	0.9	610	270	1.39	1.6

28/02/77 Engine with 508 x 457 mm propeller run for 2 h.

01/02/77 Engine run for 40 min.

10/03/77 Engine installed in XM-1A/W1 and run for 15 min whilst vibration checks were made on airframe. One cylinder retaining stud snapped off. On removal of cylinder to replace stud, it was noted that the piston crown had a different design contour from those in the earlier engines. Also the inlet and exhaust ports had been changed slightly.

18/03/77 Engine run for 10 min. Two more studs snapped off on opposite cylinder. All studs replaced with locally made EN25T studs.

27/04/77 Engine with 508 x 457 mm propeller installed in XM-1A/1 and run for 20 min taxi trial.

29/09/77 Engine run for 18 min - maximum speed obtained was 4600 rev/min.

20/10/77) Engine run for approximately 30 min at between 1800 and
21/10/77) 4000 rev/min with electronic spark ignition.

01/11/77 Engine run for 20 min with spark ignition.

23/02/78 Engine run for 16 min with CDI. Thrust at 6000 rev/min 111 N.

27/02/78 Engine test run but it failed to run for more than 15 s. Timing reset.

01/03/78 Engine test run with different ignition coils but failed to run on both cylinders.
Glow plugs fitted and engine ran well.
Spark plugs refitted but without success.

07/03/78 Engine test run to check ignition system but without success.
Glow plugs fitted and engine run for 2 min.

15/03/78 Engine run for 22 min with CDI.

16/03/78 Engine with 508 x 355 mm propeller run for 7 min with lightweight CDI and J4J spark plugs, max revolutions per minute 5800.
Engine run with heavy CDI for 10 min.

21/03/78 Engine run for 5 min to check timing and to test heavy CDI and oil cooled coils, max revolutions per minute 5900.

22/03/78 Engine run for 12 min using oil cooled coils max revolutions per minute 5700. Fuel consumption 2.9 L/h.
Engine run for 8 min and fuel consumption 4.0 L/h.

06/04/78 Engine with CDI and Kolbo 508 x 355 mm propeller installed on XM-1A/3 and run for 5 min at AD.
Engine run for 22 min for taxi trials at Edinburgh.

07/04/78 Engine run for 44 min for interference checks.

12/04/78 Engine with WSRL 508 x 355 mm propeller run for 16 min for carburettor tuning, max revolutions per minute 5800.

13/04/78 Engine removed from XM-1A/3 and installed on test rig.

Engine test run with CDI for 33 min.

Time: 9.14 am
Propeller: WSRL 508 x 355 mm

(rev/min)	Thrust (N)	Torque (N m)	Power (HP)	Power (kW)
5800	95	4.3	3.5	2.6
5000	76	3.3	2.3	1.7
4500	60	2.5	1.6	1.2
4000	48	2.0	1.1	0.8
3500	44	1.5	0.7	0.6
3000	31	0.7	0.3	0.2

Fuel consumption at 5800 rev/min 4.7 L/h.

Time: 11 am
Propeller: Kolbo 508 x 355 mm

(rev/min)	Thrust (N)	Torque (N m)	Power (HP)	(kW)
7000	110	4.1	4.1	3.0
6500	100	3.5	3.2	2.4
6000	84	2.9	2.5	1.8
5500	73	2.5	2.0	1.5
5000	62	2.1	1.5	1.1
4500	50	1.6	1.0	0.7
4000	40	1.3	0.7	0.5
3500	28	0.7	0.4	0.3

Fuel consumption at 7000 rev/min 6.1 L/h.

17/04/78 Engine with Kolbo 508 x 355 mm propeller fitted to XM-1A/3. Engine run for 25 min for systems checks at AD. Propeller damaged when moving over rough ground.

18/04/78 Propeller repaired, rebalanced and refitted. Engine run for 12 min at AD.

19/04/78 Two taxi tests at Edinburgh. Engine running time 29 min.

20/04/78 Engine run for 68 min for nine taxi tests and lift off trials at Edinburgh. Engine revolutions per minute at idle 3000. Engine revolutions per minute at mid throttle 5100. Engine revolutions per minute at full throttle was 6900.

26/04/78 New Kolbo 508 x 355 mm propeller fitted. Aircraft damage repaired.

27/04/78 Engine run for 5 min. Full throttle 6900 rev/min and idle 2400 rev/min. Engine run for 6 min. Max revolutions per minute 7000 and idle 2400 rev/min.

28/04/78 Taxi tests at Edinburgh. Too windy for flight. Engine run for 48 min, max 7000 rev/min, idle 2400 rev/min.

02/05/78 Engine run for 30 min at Edinburgh, max revolutions per minute 6900.

Flight trial A/3 No 1 for 7 min.

Average fuel consumption 2.7 L/h.

11/05/78 Engine run for 5 min at Edinburgh but would not reach max revs. Timing checked and found to be out by 7° towards retard.

Keyway cut on disc which was refitted. Engine was difficult to start on methanol. Engine ran well when primed with petrol.

12/05/78 Engine run for 13 min, max revolutions per minute 7200. Engine bolts drilled for wire locking.

17/05/78 Engine run at AD for 15 min. Very difficult to start. Carburettor refitted and adjusted, engine ran well, max revolutions per minute 7000.

Engine run for 14 min at Edinburgh for taxi tests and one lift off. Propeller damaged on touch down. Replaced with WSRL 508 x 355 mm propeller, max revolutions per minute 5300.

At AD, replaced by Kolbo 508 x 355 mm propeller. Engine run for 4 min, max revolutions per minute 7000.

18/05/78 Engine run for 2 min, max revolutions per minute 7200.

19/05/78 Engine run for 4 min, too windy for flight.

22/05/78 Engine run for 2 min at AD, max revolutions per minute 6900.

Flight trial A/3 No. 2 for 10 min.

Flight trial A/3 No. 3 for 9 min.

Flight trial A/3 No. 4 for 3 min.

Flight trial A/3 No. 5 for 2 min.

Engine run for 52 min at Edinburgh, max revolutions per minute 7000, for trials.

24/05/78 Engine run at AD for 2 min.

Flight trial A/3 No. 6 for 9 min.
Nose wheel loose and new nose wheel assembly fitted.

Engine run at Edinburgh for 33 min for trials.

25/05/78 Engine run at AD for 2 min.

Engine run at Edinburgh for 43 min for taxi tests to check nose wheel. At end engine was running erratically probably due to dirt in carburettor.

29/05/78 Engine removed from XM-1A/3 and completely dismantled. Big-end journals - front 0.0025 mm and rear 0.005 mm ovality. All parts cleaned.

30/05/78 Engine re-assembled with modified ignition ring to give more retardation for starting and to give a positive lock screw to hold ring in flight position.

01/06/78 Engine refitted to XM-1A/3.

02/06/78 Engine ran intermittently for 5 min. Fault in ignition causing one cylinder to fire only occasionally.

07/06/78 Engine run but still misfiring. Engine removed and broken wire to ignition pick up found and repaired. Engine ran well.

08/06/78 Engine refitted to XM-1A/3 and run for 6 min.

12/06/78 Engine run for 10 min. Carburettor tuned and max revolutions per minute 6700.

13/06/78 Engine run at AD, max revolutions per minute 6700.

Flight trial A/3 No. 7 for 6 min.

Flight trial A/3 No. 8 for 3 min.

Flight trial A/3 No. 9 for 2 min.

On final landing some damage to fuselage. Engine and ignition removed for inspection.

Total engine running time 45 min.

14/06/78 Engine refitted to XM-1A/3 after repairs to body including a new nose wheel.

15/06/78 Engine run at AD for 5 min, max revolutions per minute 6700.

Flight trial A/3 No. 10 for 8 min.

Flight trial A/3 No. 11 for 5 min.

Flight trial A/3 No. 12 for 7 min.

Flight trial A/3 No. 13 for 4 min.

Flight trial A/3 No. 14 for 7 min.

Flight trial A/3 No. 15 for 8 min.

Flight trial A/3 No. 16 for 4 min.

Flight trial A/3 No. 17 for 6 min.

Engine running time at Edinburgh was 104 min.

19/06/78 Engine run at AD for 5 min. max revolutions per minute 6600.

Flight trial A/3 No. 18 for 6 min.

Flight trial A/3 No. 19 for 3 min.

Flight trial A/3 No. 20 for 8 min.

Engine running time at Edinburgh was 35 min.

20/06/78 Engine run at AD for 5 min, max revolutions per minute 6800.

Flight trial A/3 No. 21 for 5 min.

Flight trial A/3 No. 22 for 3 min.

Flight trial A/3 No. 23 for 7 min.

Flight trial A/3 No. 24 for 4 min.

Flight trial A/3 No. 25 for 6 min.

Flight trial A/3 No. 26 for 5 min.

Flight trial A/3 No. 27 for 9 min.

Engine running time at Edinburgh was 70 min.

21/06/78 Engine run at AD for 3 min, max revolutions per minute 6700.

Flight trial A/3 No. 28 for 6 min.

Flight trial A/3 No. 29 for 2 min.

Flight trial A/3 No. 30 for 7 min.

Flight trial A/3 No. 31 for 5 min.

Flight trial A/3 No. 32 for 8 min.

Engine running time at Edinburgh was 73 min.

11/07/78 Engine run at AD for 5 min. Plugs changed from J4J to XE-J6 due to breakdown of connectors. Engine run for 2 min but would not maintain maximum speed.

12/07/78 Engine run for 8 min with silencers.

13/07/78 Engine run for 5 min but power dropped off after 3 min at full throttle.

25/09/78 Engine run for 8 min to check screened spark plugs KLG SFH-100, max revolutions per minute 6800. Engine and ignition OK.

29/09/78 Engine started and ran very roughly at full throttle. Engine running time was 10 min.

Engine removed from XM-1A/3 as difficult to start due to wear.

30/09/78 Screened plugs fitted.

10/10/78 Engine dismantled for inspection.

11/10/78 Engine re-assembled with new big-end bearings. Original rollers in bearings worn down 0.001 inches.

11/06/79 Engine fitted to test rig but could not be started. Ignition disc coated with oil and sent to AES for slot to be widened to 0.76 mm.

30/08/79 Hard to start, run for 25 min but roughly.

Total running time of engine, serial number 0031, was approximately 23 h including about 15 h with spark plug ignition.

IV.4 Fourth Kolbo engine, No. 0032

16/03/77 Engine run for 30 min.

17/03/77 Engine run for approximately 1 h. Cylinder stud snapped off. All studs replace with locally made EN25T studs.

06/04/77 Engine run for 10 min. Revolutions per minute 5700 dropped to 4900 when hot. Adjustments were made to the carburettor but these made no appreciable difference to the speed. Another carburettor was fitted, but this also proved unsuccessful.

13/04/77 Engine run for 59 min using 6 L of fuel.

Time:	11.30 pm	12.30 pm
Ambient temperature:	18°C	19°C
Pressure:	1023 HPa	1023 HPa

Propeller size (mm) (inches)	508 x 457 (20 x 18)	419 x 457 (16½ x 18)	356 x 457 (14 x 18)	330 x 457 (13 x 18)
rev/min full throttle	5800	7000	8600	9900
Torque N m	4.4	4.3	4.2	3.8
Power kW	3.5	4.2	5.0	5.3
Horsepower HP	2.6	3.1	3.7	3.9
rev/min 3/4 throttle	4900	5500	6300	6800
Torque N m	3.0	2.7	2.2	1.7
Power kW	2.1	2.0	1.9	1.6
Horsepower HP	1.6	1.5	1.4	1.2
rev/min 1/2 throttle	3900	4200	4800	5400
Torque N m	1.3	1.6	1.25	1.3
Power kW	0.7	1.0	0.80	1.0
Horsepower HP	0.5	0.7	0.60	0.7

Average fuel consumption was 6.1 L/h.

14/04/77 Engine run to check fuel consumption with glow plugs.

Propeller: 508 x 457 mm

(rev/min)	Run (s)	Fuel used (mL)	(L/h)
5700	198	270	4.91
5700	192	270	5.06
5000	214	270	4.54
4500	260	270	3.74
4000	270	270	3.60
3500	291	270	3.34
3000	474	270	2.05

15/04/77 Engine mounted on rig to check operation of carburettor with engine in various attitudes. Carburettor with positive opening needle valve gave the same performance as the valve which was not linked up. Engine running time 35 min. Maximum revolutions per minute still only 5700.

25/05/77 Carburettor dismantled and cleaned. Engine run for 10 min.

26/05/77 Engine run for 30 min with fuel mix of Methanol 77%, Nitro-methane 3%, Oil 20%. Maximum revolutions per minute obtained when hot 4900.

14/07/78 Engine fitted to XM-1A/W1.

29/09/78 Engine with 508 x 355 mm propeller fitted to XM-1A/3 and ran well.

03/10/78 Engine would not start. Carburettor changed and engine run for 6 min. Original carburettor cleaned, serviced and refitted but not satisfactory.

04/10/78 Engine run at AD for 4 min.

Engine run at Edinburgh for 10 min but fault in control system. Trials cancelled.

Plugs changed from KLG type to J4J. Engine run at AD for 20 min.

05/10/78 Engine run at AD for 5 min.

06/10/78 Engine run at AD for 8 min.

10/10/78 Engine run at AD for 5 min to check revolutions per minute system in XM-1A/3, max revolutions per minute 6900.

12/10/78 Engine run at AD for 3 min to check revolutions per minute system.

Flight trial 10 A/3 No. 33. Crashed on take off.

11/06/79 Engine fitted to test rig after being fitted with CD ignition disc with slot of 0.79 mm. Engine run for 3 min.

12/06/79 Engine run for 15 min for starting adaptor test.

24/06/79 Engine run for 15 min for further starting adaptor test.

30/08/79 Engine run for 25 min for calibration check. Maximum revolutions per minute 6600 idle revolutions per minute 1400. Fuel 85% methanol, 5% nitro-methane and 10% oil.

Time:	3 pm
Ambient temperature:	13.1°C
Pressure:	1018.3 HPa
Propeller:	Kolbo 508 x 355 mm
Fuel:	methanol 85% nitro methane 5% castor oil 10%

(rev/min)	Thrust (N)	Torque (N m)	Power (HP)	(kW)
3200	20	1.0	0.4	0.3
3500	26	1.2	0.5	0.4
3900	34	1.5	0.8	0.6
4500	43	1.9	1.2	0.9
5100	53	2.3	1.7	1.2
5400	64	2.5	1.9	1.4
6400	93	3.7	3.3	2.5
6600	93	3.8	3.5	2.6
5400	63	2.5	1.9	1.4
5100	53	2.3	1.7	1.2
4400	40	1.7	1.1	0.8
4100	34	1.5	0.9	0.7
3500	26	1.2	0.6	0.4
3100	19	1.0	0.4	0.3
2600	14	0.7	0.3	0.2

Start was satisfactory and engine ran smoothly.

Total running time of engine, serial number 0032, was approximately 6 h, including about 1 h with spark plug ignition.

IV.5 Fifth Kolbo engine, Serial No. 0033

03/04/78 Engine received with ignition and spares.

10/04/78 Engine sent to our workshop to have ignition pick-off point moved 10° to change direction of rotation (pusher).

01/05/78 Prepared for test run with Kolbo ignition and 14/1 petrol mix.

02/05/78 Engine run for 10 min.

03/05/78 Engine run for 2 min but was very difficult to start. Ignition components changed but no improvement.

04/05/78 Ignition pick-off changed back to original position.

19/05/78 New backplate to suit WSRL ignition fitted.

31/05/78 Engine with WSRL ignition fitted to test rig but failed to start with petrol mix as fuel.

14/07/78 Engine fitted to XM-1A/W1.

15/09/78 Modifications to engine mounting.

Total running time of engine, serial number 0033, was 12 min.

APPENDIX V

PROBLEMS ENCOUNTERED WITH THE KOLBO D238 ENGINE

The running histories of the five Kolbo engines are recorded in Appendix IV.

V.1 Piston burn-through

On two occasions the top of the piston collapsed, once while the engine was running, and once while starting up, see figures V.1 to V.4. This appendix includes a report on the investigation of these failures. A new 10% thicker and higher density cast aluminium alloy piston was made by our workshops to solve the problem, figure V.5.

V.2 Redesign by manufacturer

The two Kolbo D238 engines purchased in 1977, serial numbers 0031 and 0032, could not be made to run faster than about 5200 rev/min despite checking all aspects of engine running, fuel flow, fuel mixture etc. On disassembly, it was found that the pistons had been redesigned with pronounced doming and with relocation of the cylinder ports. A letter with the test results from all four engines was sent to the manufacturer asking for comments but no reply has yet been received.

V.3 Engine vibration

Engines with reed valves and glow plug ignition can be operated in either direction - such is the case with the Kolbo D238. The engine is started by applying current temporarily from an electrical power source to the glow plug coils and flicking the propeller to develop cylinder compression and fuel ignition and the engine generally runs in the opposite direction to which the propeller was flicked. The source of power is then disconnected and the engine runs on a two stroke cycle because the glow plug element is heated by catalytic effect as cylinder pressure increases until it reaches a sufficient temperature to ignite the fuel mixture as top dead centre (TDC) is approached. Because the conditions for ignition are generally not identical in each of the two cylinders with glow plug ignition, the resulting combustion forces are seldom balanced. This generates a higher level of vibration than would occur with simultaneous ignition timing.

V.4 Shaft reversal

The ignition timing with glow plugs can occasionally become so advanced that peak pressure is developed in the cylinder before the piston gets over top dead centre (TDC). On several occasions, the Kolbo D238 has suddenly changed its direction of rotation while running at speeds of more than 2000 rev/min. The normal idling speed is 2000 rev/min with a maximum static speed of 6000 rev/min at full throttle with a 508 mm x 457 mm pitch propeller.

V.5 Factors contributing to shaft reversal

Any condition which promotes the early ignition of the fuel can contribute to shaft reversal. Some of these conditions are as follows;

(a) excess heat retention in a glow plug,

(b) too lean a fuel mixture,

(c) high initial fuel temperature,

(d) use of fuel with excessive nitro-methane content,

(e) high ambient air temperature,

(f) insufficient external cooling airflow over the cylinders, and

(g) temperature rise due to rpm reduction to idle after considerable time at full throttle.

V.6 Effect of reversal

The inertia loads associated with engine reversal produced high forces through the moving components and caused failures at the weakest points in the chain - namely the four bolts retaining the propeller to the metal face plate and the keyway fixing the face plate to the shaft. Attachment V.2 includes the report on the investigation of these failures. Several changes were made to overcome this problem but the loads were too high. It was decided to change to a spark ignition system to avoid this reversal problem. In the meantime while the spark ignition system was being developed, additional changes were made to allow temporary continued use of the glow plug ignition.

V.7 Shaft wear

An investigation of a failure of a Kolbo engine (no serial number) showed that one of the needle bearings in the connecting rod big-end had broken. A piece of this very hard steel had been sucked through the fuel transfer port and wedged between the piston head and the cylinder wall, causing a deep score up the cylinder. The crankshaft was examined by AEL Foundry Section and the result is given in Attachment V.3. Measurements of the shaft, which had been produced by AEL, showed considerable ovality and surface pitting on the bearing contact area (up to 0.3 mm ovality for 10 h total running time). The crankshaft had been machined from Bohler Ace steel and nitrided to provide hard, wear-resistant bearing surfaces and to improve fatigue resistance. Micro-examination by the AEL Foundry Heat Treatment Section (Attachment V.4), revealed 'sub-surface cracking, parallel to the surface, typical of a type of failure common to anti-friction bearings where the stresses are caused by pure rolling. This type of sub-surface cracking is generally attributed to the presence of non-metallic inclusions, in this case iron nitride'. Tests showed that the surface hardness was about 1000 HV with an effective case depth of 0.2 mm.

Shafts provided by the engine manufacturer have shown signs of pitting but much less ovality (Attachment V.4) than the shaft manufactured by AEL. The Metallurgist has suggested that, for any shafts made in the future the surface hardness be reduced to about 850 HV and the effective case depth doubled to 0.4 mm. Lower nitrogen content at the surface should reduce the formation of nitrides, thus avoiding high stress levels under the rolling loads from the needle bearings. This shaft ovality arises from the random loads near top-dead-centre when using glow plug ignition.

V.8 Idling speed

In addition to the piston change mentioned in Section V.1, other modifications were made and the decision taken to increase the idling speed from 2000 rev/min to 3000 rev/min in the hope that the additional speed and inertia would ensure that the piston would always get over top-dead-centre.

ATTACHMENT V.1

Investigation of Kolbo Engine Piston Failure

WRE Foundry Note 1/2/77

Two pistons and two gudgeon pins were submitted for examination to determine the cause of failure of the piston crowns and the cause of the excessive wear evident on one of the pins.

Pistons

1. The first piston examined was original equipment in the motor. Its exact composition was not determined but was indicated to be 6000 series aluminium alloy by spot test. The microstructure indicated that the stock was cold rolled prior to machining and heat treatment. The hardness was measured at 105 HV. The grain size was large with grain elongation along the axis of the piston. In many cases a single grain boundary extended through the entire crown thickness. Heat treatment had produced precipitate free zones adjacent to the grain boundaries, with some precipitates at the grain boundaries.

The cracks were all intergranular and contained what appeared to be corrosion products. The majority of the cracks were radial in orientation and initiated in the upper, compressive face of the crown, extending, in some cases, to one half of the crown thickness. No cracks were found in the lower, tensile face of the crown.

2. The other piston was fabricated from cast 3L52 aluminium alloy, machined and heat-treated. The hardness was measured at 160 HV. Microscopic examination revealed the grain size to be much smaller than that of the other piston. However, the degree of shrinkage porosity was high, especially in the critical area near the centre of the crown. The two cracks found in the crown initiated in the lower, tensile face and were radial and at approximately right angles to each other.

Pins

1. The two pins were tested for surface hardness and sections were then cut, polished and etched to reveal the case depth. The following results were obtained:

Specimen	Hardness (HV2.5)	(Rc)	Case depth (Thou)
AES pin	590	55	12
Original pin	870	66	15

2. Close examination of the pin manufactured by our workshop revealed that the surface had been deformed plastically with few signs of cracking. The general appearance of the pin suggested that the loading had been very uneven, indicating that the 'little end' of the connecting rod may not have been aligned correctly with respect to the gudgeon pin.

3. The original pin was in a satisfactory condition for the number of hours it had been in use. No signs of misalignment were seen.

Discussion

Pins

Although the surface hardness of the locally made pin was greater than that specified in the drawing (45 to 50 Rc), it was less than that of the original pin. The case depth was also slightly shallower than in the original pin. These factors, combined with the apparent misalignment of the roller bearings on the pin, caused the excessive wear.

Pistons

1. The cracks found in the crown of the original piston are probably due to stress corrosion cracking. Aluminium alloys are prone to this type of failure in environments containing chlorides or other halides, and cracking is always intergranular. It was not possible to identify the specific corrodent in this case, but it may have been a constituent of the fuel as a combustion product, unless the motor was used extensively near the sea. This explanation is supported by the absence of cracks in the lower, tensile face of the crown, where the surface is always covered with an oil film, providing a high degree of corrosion protection.

2. The nature of the cracks in the locally made piston, and the conditions under which failure occurred, indicate this to be a simple overload failure, where the excessive pressure, caused by compression of fuel introduced directly into the combustion chamber through the exhaust port, caused the collapse of the piston crown. No evidence of the cracking found in the other piston was apparent.

Conclusion

1. The propensity to stress corrosion cracking can be decreased by utilising a material with a finer grain size without a preferred orientation, and by proper heat treatment. It can be completely removed by using a material not prone to stress corrosion cracking in the particular environment, or by removing the particular corrodent from the environment. The absence of these cracks in the 3L52 alloy piston suggests that this may be a suitable alternative material in this regard.

2. The presence of shrinkages porosity in the thin, highly stressed crown should be avoided at all cost. A technique for solidification under pressure, to eliminate such porosity, is currently under investigation at the Foundry (in 1977). This technique could readily be applied for the production of ingots for machining.

It is suggested that replacement pistons be machined from cast 3L52, solidified under pressure. A period of about four weeks will be required to set up the equipment, (as specified in 1977).

Increasing the crown thickness would decrease stresses and thus prolong the life of the piston.

3. Replacement pins should be manufactured and heat-treated to correspond more closely with the specifications of the original pin. The alignment of the connecting rods should be checked and corrected.

ATTACHMENT V.2

Investigation of Kolbo Engine Propeller Failures

WRE Foundry Note 29/11/77

Three propellers, one hub and associated securing bolts for a glow plug ignition Kolbo motor were presented for investigation. Of the three propellers, two were manufactured in the AEL pattern shop from spruce and were modelled on the third propeller which was supplied by the manufacturer. The two locally manufactured propellers had tailed in service due to the motor backfiring and running backwards. The third propeller had been used but was still intact and was provided for comparison.

The securing bolts were of three types. Firstly, the undamaged manufacturer's bolts were provided as a standard. The second type were "off the shelf" Unbrako bolts which had failed in service and the third type were bolts which had also failed and which had been made by our workshop from EN25T molybdenum steel.

The hub with remnants of four broken bolts still attached, was also presented for examination.

Investigation

The aims of this investigation were:

(a) To determine relative hardnesses of the three propellers supplied and to suggest a timber, alternative to spruce, which would provide a better performance in service.

(b) To determine the mode of failure of the bolts and recommend a material which would withstand this type of loading without failure.

(c) To suggest any other means by which the failure rate of these propellers could be decreased.

Report

After discussion with the customer, it was concluded that the cause of failure of the propellers was the characteristic tendency of the motor concerned to backfire and begin running backwards. The stresses imposed on the propeller and securing bolts by this behaviour are understandably severe and represent a load far in excess of the normal operating load.

Bolts

The fracture surface of each bolt was examined to determine the probable mode of failure. Each bolt, except one, hal failed under tension in the threaded section. Some of the higher strength Unbrako bolts showed signs of two cycle fracture, ie the bolt did not fail completely on the first overload. The single bolt which had not failed in the thread had been bent and torn, in a single action, probably by the propeller still attached to the hub after the initial failure. Typical hardness values, for each type of bolt appear below.

Bolt type	Hardness
Original bolt	450 HV30
Unbrako	430
WRE bolts	300

Propellers

Visual inspection of each of the spruce propellers revealed that the timber had split along the grain through the hub, between securing bolt holes and across the grain to the hole in the centre of the boss. Being a very straight grained timber, the spruce would offer a low resistance to splitting along the grain. The timbers were examined microscopically and it was observed that the original propeller was made from a harder wood than the spruce. This was confirmed by hardness tests, the results of which appear below. Values represent force (N) required to indent a 12.6 mm dia ball to a depth of 1 mm.

Timber	Force (N)
Original	580
Spruce	385
Coachwood	410
Myrtle Beech	510

Conclusion

Bolts

It was concluded that as failure was apparently due to impact type loading a material with a higher impact strength, as opposed to a high hardness and tensile strength, be used for the bolts. It was suggested that the bolts have a hardness of about 400 HV. This would ensure a tough structure with adequate strength. It was suggested by the customer that the problem may be lessened by increasing the number of securing bolts from 4 to 6, by including two bolts along the principal axis of the propeller. Although this was not thought to be detrimental to the performance of the propellers, it was suggested that a greater benefit would be derived by rotating the location of the four securing bolt holes by 45° in the boss. This would then remove the holes from the areas of maximum stress in the boss and place them in the areas of minimum stress.

Propellers

Coachwood was selected as a suitable replacement material for the propellers. It had the highest specific strength of any timbers available in Adelaide at the time of this investigation. A quantity of this timber was purchased with the agreement from the customer, and a number of trial propellers were being made at the time of writing. It was strongly recommended that the securing bolt holes be relocated as described above. Myrtle Beech, which is a harder but heavier timber has been selected as a second alternative.

General

This problem appears to be due to the movement of the propeller on the hub causing the fracture of propellers and securing bolts. Two general remedies are available, *viz:* to improve the strength of the propellers and obtain a more secure mounting method; and to eliminate the tendency for the motor to run backwards. It was suggested that this tendency may be minimised by offsetting the gudgeon pin in the piston by 0.8 to 1.0 mm. This is entirely possible as the pistons are machined by our workshop from squeeze cast billets produced by the AEL Foundry.

ATTACHMENT V.3

Investigation of Kolbo Engine Crankshaft Failure

AEL Foundry Section Note of 21/5/76

Kolbo engine crankshaft

Wear was evident on the bearing surface (throws) of the crankshaft.

A build-up of chrome has been applied to the keyway and tapered shaft, and some lift off of the chrome occurred. High octane two stroke fuel has been used (80% methyl alcohol, 10% nitro-methane, 10% castrol). The thread has not been blued back to improve toughness. Vickers Hardness Tests were conducted using various loads and these indicated that a case hardening technique was probably employed.

Results were 820 HV5, 770 HV10, 660 HV30. Hardness on the worn bearing surface was 770 HV10. Spot tests were carried out using ASTM Technical Publication 550 in an endeavour to classify the metal.

The Kolbo crankshaft responded as a nickel-chromium-molybdenum steel, similar to a 4340 type steel. A carbon spot test on the surface gave no reaction. This indicated that if a case hardening procedure had been used then nitriding had been employed.

The 4340 type alloy steels can be nitrided and a micro section confirmed this to be so.

Examination of the bearing surface

The wear appears to be uniform across the width of the throw indicating that misalignment was not the cause. Wear was confined mainly to an area of the throw as could be expected by the downward thrust contact for the piston.

Conclusion

The material probably used, ie a high tensile steel, nitrided; is a good choice for a crankshaft of this nature. The use of chromium plating* as a build up at the shaft and keyway area is questionable as high underlaying tensile stress can be set up which can reduce fatigue life.

The bearing or throw hardness is still good in the worn area, therefore a breakdown of the case is not indicated. Wear may be attributed to either insufficient lubrication or too small a bearing surface for the load applied.

The use of a nitriding steel containing Al as an alloying agent (ie Bohler Ace) would enable case hardnesses of approximately 1000 HV and proportionally more wear resistance.

*Plating added at AEL Electro-finishing Section to bring repaired crankshaft up to required diameter.

ATTACHMENT V.4

Failure of Nitrided Kolbo Crankshaft Journals

AEL Foundry Note of 15/8/78

A model aircraft crankshaft had shown signs of severe pitting of the big end journals after only a few hours of service. The crankshaft had originally been machined from Bohler Ace stock and nitrided to provide hard, wear-resistant bearing surfaces and to improve fatigue resistance.

Visual examination revealed that surface spalling had occurred on the "big end" journals. A journal was cut from the crankshaft and prepared for micro examination. A micrograph of a typical damaged area appears in figure V.6. The sub-surface crack, which is parallel to the surface, is typical of a type of failure common to antifriction bearings where the stresses are caused by pure rolling. This type of sub-surface cracking is generally attributed to the presence of non-metallic inclusions, in this case iron nitride.

Figure V.7 depicts an undamaged section of the surface which has been etched to reveal the total case depth. The hardness values corresponding to the indentations appearing in figure V.7 appear in graphical form at figure V.8.

These results indicate an extremely high surface hardness grading down, through a relatively thin case, to a soft case. The total case depth is about 0.40 mm (0.016 inches) with an effective case depth of 0.20 mm (0.008 inches). To overcome this type of failure, it is suggested that the total case depth be increased to at least 0.60 mm (0.024 inches) with an effective case depth of about 0.40 mm (0.016 inches), and to the surface hardness to decreased to about 850 HV. This lower surface hardness should be achieved by decreasing the nitrogen content near the surface, thus reducing the possibility of forming nitrides near the surface. An investigation is currently under way to establish a means to achieve these requirements.

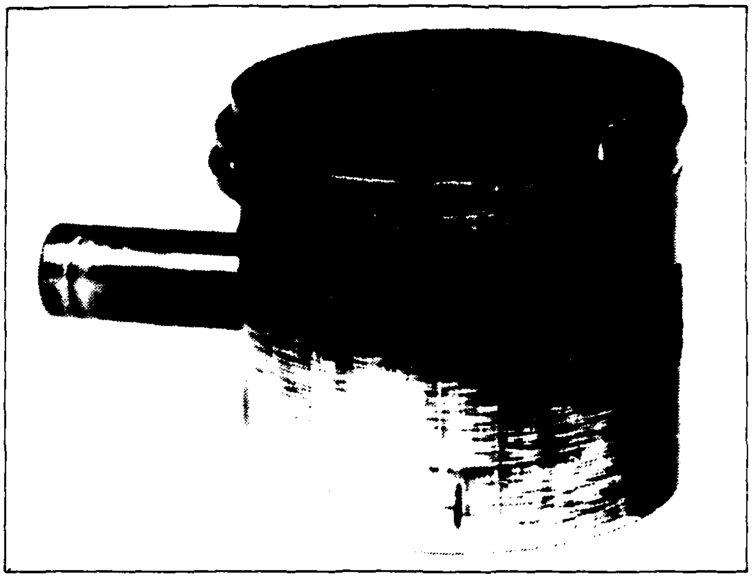

Figure V.1 Kolbo piston with burn through (N76/346)

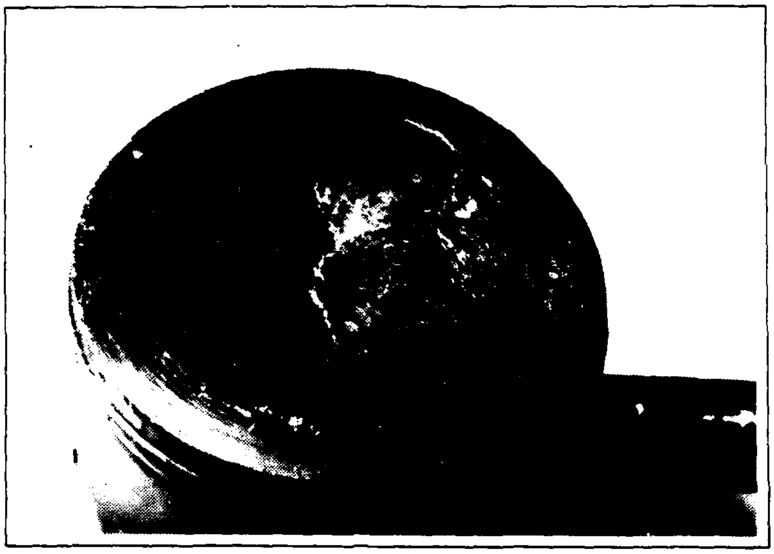

Figure V.2 Top of Kolbo piston (N76/347)

Figure V.3 Close up of top of Kolbo piston (N76/349)

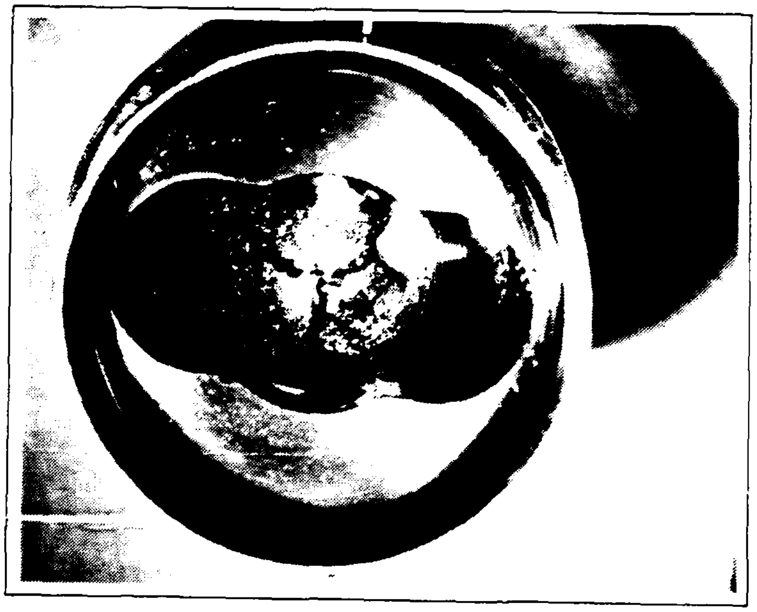

Figure V.4 Bottom view of Kolbo piston (N76/348)

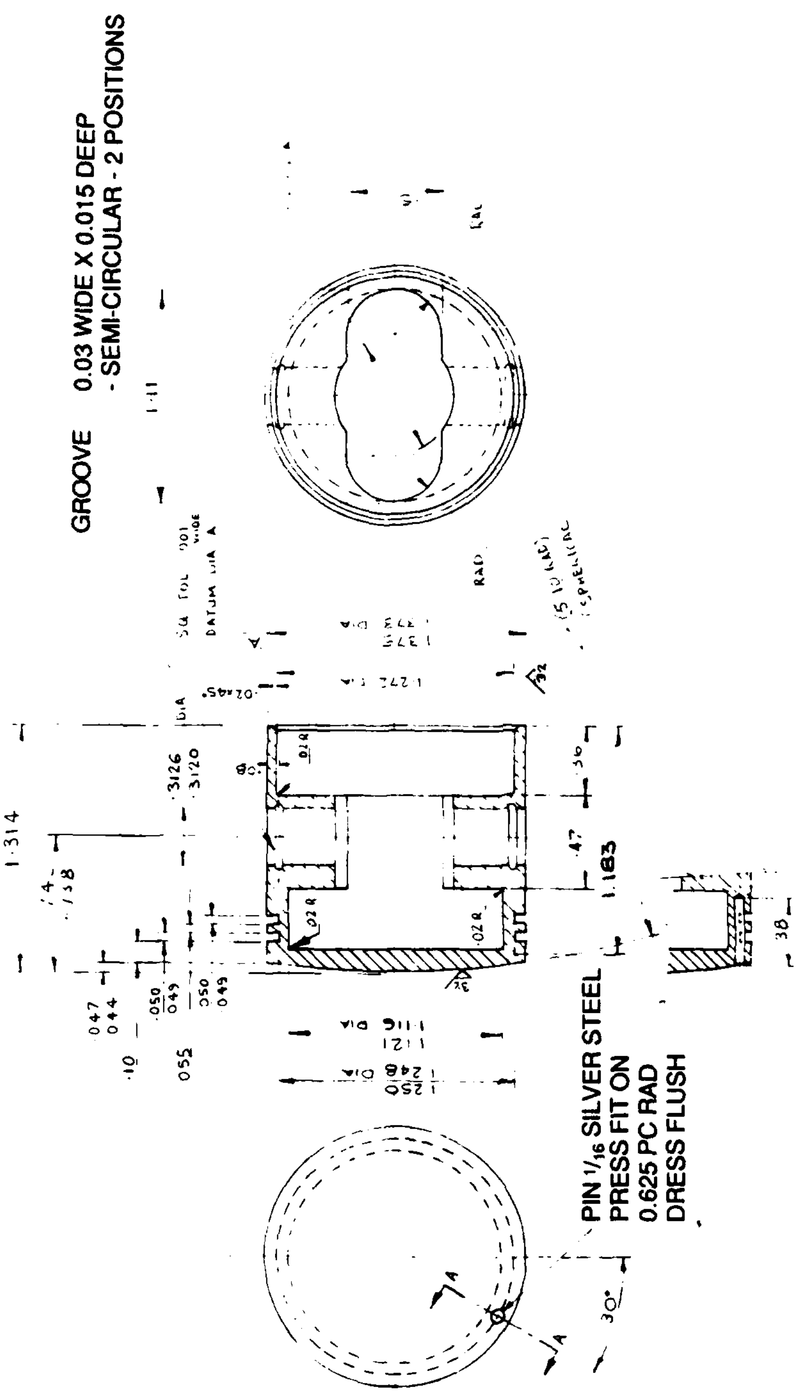

Figure V.5 New aluminium alloy piston for Kolbo D238 engine

Figure V.6 Typical failure of nitrided crankshaft journal, times 170

Figure V.7 Undamaged surface of crankshaft journal, times 170

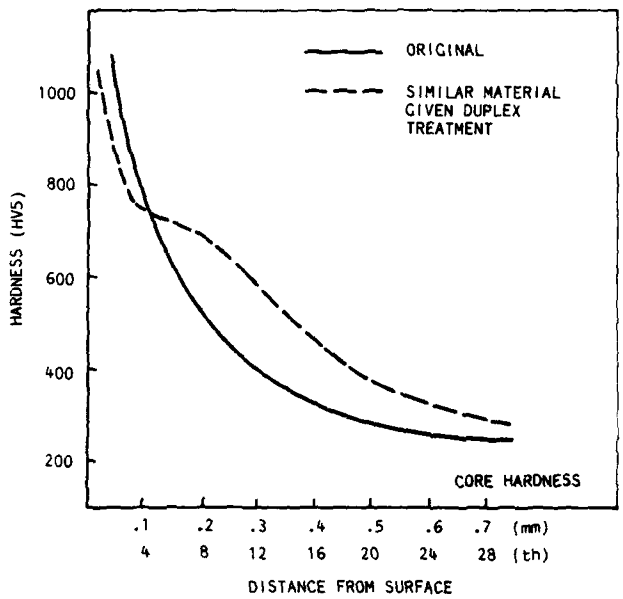

Figure V.8 Case hardness profile

APPENDIX VI

DH ENTERPRISES DYAD 160 ENGINE SPECIFICATION

Engine type	: Twin cylinder, 2-stroke cycle, opposed twin, simultaneous firing, air cooled
Bore	: 50.8 mm (2.00 inches)
Stroke	: 38.6 mm (1.52 inches)
Displacement	: 161 cc
Compression ratio	: 9.5/1
Horsepower	: 7.5 kW (10 BHP)
Mass	: 4.1 kg (9 lb) including CD ignition (less batteries)
Bearings	: 4 roller bearings on three piece crankshaft with single piece connecting rods
Carburettor	: Walbro (two)
Ignition	: Spark plug (Champion XEJ-6 used by AD) (two)
Fuel consumption	: Approx 0.36 L/HP/h using 24/1 Petrol/Oil mix
Rotation	: Clockwise
Length	: 143 mm (5.63 inches)
Width	: 440 mm (17.3 inches) including spark plugs and leads
Height	: 192 mm (7.56 inches) including carburettor

See figures 7, 8, 9, 10 and 11.

APPENDIX VII

ENGINE ADJUSTMENT PROCEDURE - DYAD 160

There are two adjustment screws (high speed (H) and low speed (L) needle valves) on the side of the carburettor and three throttle settings at which these adjustments to engine operation are made. Since there is interaction between the fuel jets in the carburettor at various throttle settings, several (three or more) repetitions of adjustment must be made in order to obtain proper operation of the engine over the entire operating range. Proceed as follows:

(a) With engine at fast idle (approx 2000 rev/min) adjust screw L (low speed) until engine is heard to run at maximum revolutions per minute and then turn screw counter clockwise (to the left) 1/16 turn (to slightly richen mixture).

(b) Open throttle to maximum and adjust screw H (high speed) until engine is heard to run cleanly at maximum revolutions per minute and then turn screw counter clockwise (to the left) 1/16 turn (slightly richens mixture).

(c) Reduce throttle to about 5000 rev/min (approximately 40% open throttle) and adjust screw L (low speed) for maximum revolutions per minute and then richen it (turn to left) about 1/16 turn.

(d) Again open the throttle to maximum and adjust screw H (high speed) for maximum revolutions per minute and then richen it (to the left) about 1/16 turn.

(e) Now return engine to idle and repeat sequence of adjustment (steps a through d above), at least two (2) more times, until position of both adjustment screws remain the same throughout the complete sequence.

If correctly adjusted, the engine will now idle smoothly and reliably at 1500 to 1800 rev/min, respond very quickly to throttle changes, operate reliably and economically throughout the throttle range and stop when throttle is fully closed.

APPENDIX VIII

DYAD 160 ENGINES - RUNNING HISTORIES

VIII.1 First Dyad engine Serial No 1

Date	Min	
01/06/78		Assembly completed with Tillotson carburettors.
07/06/78		Engine with 508 x 380 mm (20 x 15 inches) propeller fitted to test rig.
08/06/78	5	Engine in test rig run. Fuel mix 20/1.
09/06/78	10	Engine run revolutions per minute 7500 max - faulty ignition, cut at full throttle.
	8	Engine run revolutions per minute 7500 max - faulty ignition, cut at full throttle.
	17	Engine run revolutions per minute 7500 max - faulty ignition, cut at full throttle.
12/06/78	10	Engine run. Ignition pulse rate test. Ignition fault, cut at full throttle.
16/06/78		WSRL CDI system fitted to engine.
23/06/78	10	Engine run. Engine stopped due to broken wire in ignition system. Repaired.
27/06/78	31	Engine run for ignition system checks.
05/07/78	10	Revolutions per minute counter fitted to test rig. Engine run for RPM counter checks.
06/07/78	55	Engine test run with WSRL CDI and J4J spark plugs.

Propeller : 508 x 380 (20 x 15) (narrow chord tip)

(rev/min)	Thrust (N)	Torque (N m)	Power (HP)	Power (kW)
7800	-	10.7	11.7	8.7
7000	-	8.4	8.3	6.2
6500	189	7.1	6.4	4.8
6000	153	6.2	5.2	3.9
5500	144	5.3	4.1	3.1
5000	126	4.5	3.1	2.3
4000	75	2.5	1.4	1.0
2800	42			

Thrust measuring system unserviceable and suspect for rest of thrust readings.

Fuel consumption - 8 L/h.

Date	Min	
19/07/78	30	J6J plugs fitted. Engine test run on RH carburettor only.

Time: 3.40 pm
Propeller: 508 x 380 mm (narrow chord tip)

(rev/min)	Thrust (N)	Torque (N m)	Power (HP)	Power (kW)
6900	155	8.0	7.7	5.7
6500	144	7.3	6.7	5.0
6000	124	6.7	5.6	4.2
5500	108	5.3	4.1	3.1
5000	90	4.8	3.4	2.5
4500	70	4.1	2.6	1.9
4000	56	3.0	1.7	1.3
3500	43			
2600	20			

20/07/78 2 Engine run with J6J plugs.

21/07/78 89 Engine run for measurements with 3 different propellers in gusty weather conditions.
Carburettors cleaned for each run.

Ambient temperature: 16.7°C
Propeller: 508 x 380 mm (narrow chord tip)

(rev/min)	Thrust (N)	Torque (N m)	Power (HP)	Power (kW)
7800	202	10.4	11.4	8.5
7500	180	9.7	10.2	7.6
7000	167	8.6	8.5	6.3
6500	144	7.3	6.7	5.0
6000	122	6.2	5.2	3.9
5500	100	5.0	3.9	2.9
5000	86	4.4	3.1	2.3
4500	73	3.6	2.2	1.7
4000	55	2.8	1.6	1.2
3500	49	-	-	-
3000	35	-	-	-
2500	26	-	-	-

Date Min

21/07/78
Continued

Ambient temperature: 16.7°C
Propeller: 508 x 355 mm (narrow chord tip)

(rev/min)	Thrust (N)	Torque (N m)	Power (HP)	Power (kW)
8000	202	10.2	11.5	8.6
7500	175	8.9	9.3	7.0
7000	153	7.9	7.7	5.8
6500	131	6.8	6.2	4.7
6000	109	5.5	4.6	3.4
5500	100	4.8	3.7	2.8
5000	82	3.9	2.7	2.0
4500	64	3.4	2.2	1.6
4000	49	2.5	1.4	1.1
3500	35	-	-	-
3000	26	-	-	-
2500	20	-	-	-

Ambient temperature: 16.7°C
Propeller: 508 x 330 mm (narrow chord tip)

(rev/min)	Thrust (N)	Torque (N m)	Power (HP)	Power (kW)
8200	202	10.2	11.8	8.8
8000	188	9.5	10.7	8.0
7500	162	8.6	9.1	6.8
7000	140	7.3	7.1	5.3
6500	122	6.4	5.8	4.3
6000	104	5.3	4.4	3.3
5500	93	4.9	3.8	2.8
5000	82	3.8	2.7	2.0
4500	60	3.2	2.0	1.5
3500	33	-	-	-
3000	26	-	-	-

Date	Min	
25/07/78	18	Engine run for repeat of measurements with 508 x 380 mm narrow chord tip propeller.

Propeller: 508 x 380 mm (narrow chord tip)

(rev/min)	Thrust (N)	Torque (N m)	Power (HP)	(kW)
7900	184	11.1	12.3	9.2
7500	166	9.7	10.2	7.6
7000	151	8.5	8.4	6.3
6500	133	7.3	6.7	5.0
6000	109	6.2	5.2	3.9
5500	88	5.4	4.1	3.1
5000	82	4.8	3.4	2.5
4500	55	-	-	-
4000	33	-	-	-
3500	26	-	-	-

Date	Min	
26/07/78	15	Engine run to check thrust measuring system.
	10	Engine test run.

Propeller: 508 x 380 mm (narrow chord tip)

(rev/min)	Thrust (N)
7800	180
7400	157
6700	135
6000	113
5400	91
4800	68
3800	46
2800	24

Date	Min	
29/08/78	53	Engine run.

Time: 9.03 am
Propeller: 508 x 330 (narrow chord tip)

(rev/min)	Thrust (N)	Torque (N m)	Power (HP)	Power (kW)
3500	39			
4000	43	2.5	1.4	1.1
4500	54	2.9	1.8	1.4
5000	71	3.7	2.6	1.9
5500	84	4.1	3.2	2.4
6000	98	5.1	4.3	3.2
6500	116	5.7	5.2	3.9
7000	131	6.6	6.5	4.8
7500	149	7.5	7.9	5.9
8000	166	8.6	9.7	7.2
8600	192	9.9	11.9	8.9

Time: 9.45 am
Propeller: 508 x 355 (narrow chord tip)

(rev/min)	Thrust (N)	Torque (N m)	Power (HP)	Power (kW)
3500	34			
4000	44	2.5	1.4	1.1
4500	58	3.4	2.2	1.6
5000	73	4.1	2.9	2.2
5500	86	4.9	3.8	2.8
6000	104	6.2	5.2	3.9
6500	121	7.1	6.4	4.8
7000	145	7.9	7.7	5.8
7500	152	8.9	9.3	7.0
7800	177	10.2	11.2	8.4

Date	Min	
29/08/78 Continued		Time: 10.38 am Propeller: 508 x 380 (narrow chord tip)

(rev/min)	Thrust (N)	Torque (N m)	Power (HP)	(kW)
3500	39			
4000	50	2.8	1.6	1.2
4500	68	3.3	2.1	1.6
5000	77	4.6	3.2	2.4
5500	93	5.3	4.1	3.0
6000	113	6.2	5.2	3.9
6500	129	7.1	6.4	4.8
7000	146	8.3	8.2	6.1
7500	174	9.6	10.1	7.5
8000	184	10.8	12.1	9.0

Time: 11.00 am
Ambient temperature: 14.8°C
Pressure: 1023.6 HPa
Propeller: 508 x 380 (narrow chord tip)

(rev/min)	Thrust (N)	Torque (N m)	Power (HP)	(kW)
3500	44			
4000	55	3.1	1.7	1.3
4500	69	3.8	2.4	1.8
5000	78	4.7	3.3	2.5
5500	97	5.5	4.2	3.2
6000	117	6.6	5.6	4.2
6500	133	7.3	6.7	5.0
7000	157	8.5	8.4	6.3
7500	181	10.1	10.7	7.9
7800	199	10.9	11.9	8.9

Date	Min	
11/09/78	15	Vibration test.
25/09/78		Double interupter fitted to ignition system. Timing;- advance 3 mm, retard 0.4 mm before TDC
20/12/78		Engine with 508 x 380 mm propeller fitted to aircraft XM-1A/2.
03/05/79		Engine removed from XM-1A/2. Ignition disc replaced - 0.031 slot.
	10	Engine run on test rig.
14/05/79		Engine refitted to XM-1A/2.

Date	Min	
07/06/80		CDI timing optical coupler loom replaced.
22/07/80	20	Rough running - carburettors cleaned but would not run correctly.
24/07/80	10	Engine retuned revolutions per minute 7800 max 1900 idle - run on shore supply.
18/08/80	25	Control van tests - rough running max and idle.
19/08/80	10	Engine run on shore supply with mechanical throttle. 1900 to 7800 rev/min.
20/08/80	10	Engine run for control van test.
01/10/80	14	Engine run for control van system checks - misfiring noted.
	7	Engine run with mechanical throttle on ground power supply. Satisfactory.
	10	Control van test - CDI malfunction.
02/10/80	10	CDI repaired, engine ran well.
	10	Engine run for control van check.
27/11/80	8	Engine run for control van check.
	10	Taxi trials.
15/12/80	24	Engine run for compatability tests at Edinburgh.
23/12/80	15	Engine run for field test.
20/01/81	10	Engine run for compatability tests. Engine stopped running.
21/01/81		Carburettor hoses renewed.
23/01/81	5	Engine run for control van tests.
09/02/81	15	Engine run.
	30	Engine retuned revolutions per minute 7800 max 1900 idle - flat spot at 3000.
11/02/81		Engine removed from XM-1A/2.
10/03/81	20	Engine retuned on test rig.
	35	Engine run revolutions per minute 7800 max 1900 idle. Flat spot tuned out. Carburettors cleaned. Engine installed in XM-1W/2

Total running time of engine, serial number 1, was approximately 11½ h.

VIII.2 Second Dyad engine, Serial No. 2

Date	Min	
07/07/78		Engine received.
10/07/78		Assembly completed. Bosch plugs fitted.
20/07/78	20	Engine run with DH ignition and unshielded Bosch WKA 175 T6 spark plugs. Max revolutions per minute - 5000.
24/07/78		Engine failed to start. Intermittent spark.
01/08/78		WSRL CDI system fitted.
07/08/78		Engine dismantled to remove fragment of timing gauge washer from starboard cylinder. Removed scoring. Cleaned and reassembled. 508 x 355 mm propeller fitted.
	26	Engine run on test rig.

Propeller: 508 x 355 mm (narrow chord tip)

(rev/min)	THRUST
2100	-
2900	23
3500	49
5000	74
5500	83
6000	103
6500	120
7000	138
7500	165
7800	174

Date	Min	
09/08/78	12	Fuel consumption test.
	36	Fuel consumption test - 2.4 L/h at 6000 rev/min.

Date	Min	
14/08/78	47	Engine run for measurements with three narrow chord tip propellers.

Ambient temperature: 9°C
Pressure 1029.5 HPa
Propeller: 508 x 330 (narrow chord tip)
Carburettor: Dual

(rev/min)	Thrust (N)	Torque (N m)	Power (HP)	Power (kW)
3500	32			
4000	45	2.5	1.4	1.1
4500	55	3.2	2.0	1.5
5000	65	3.7	2.6	1.9
5500	82	4.3	3.4	2.5
6000	92	5.3	4.4	3.3
6500	109	6.4	5.8	4.3
7000	127	6.6	6.5	4.8
7500	147	7.5	7.9	5.9
8000	169	9.1	10.2	7.6
8200	179	9.3	10.7	8.0

Ambient temperature: 9°C
Pressure 1029.5 HPa
Propeller: 508 x 330 (narrow chord tip)
Carburettor: Single

(rev/min)	Thrust (N)	Torque (N m)	Power (HP)	Power (kW)
3500	34			
4000	45	2.5	1.1	0.8
4500	56	3.0	1.9	1.4
5000	69	3.7	2.6	1.9
5500	86	4.6	3.5	2.6
6000	104	5.3	4.4	3.3
6500	118	6.2	5.6	4.2
6900	134	6.8	6.6	4.9

Date Min

14/08/78
Continued

Ambient temperature: 9°C
Pressure 1029.5 HPa
Propeller: 508 x 355 (narrow chord tip)
Carburettor: Dual

(rev/min)	Thrust (N)	Torque (N m)	Power (HP)	(kW)
3500	36			
4000	47	2.5	1.4	1.1
4500	57	3.4	2.2	1.6
5000	75	4.3	3.1	2.3
5500	89	5.3	4.1	3.0
6000	104	6.2	5.2	3.9
6500	121	7.1	6.4	4.8
7000	139	8.0	7.8	5.8
7500	162	8.9	9.3	7.0
7800	178	9.8	10.7	8.0

Ambient Temperature: 9°C
Pressure 1029.5 HPa
Propeller: 508 x 380 (narrow chord tip)
Carburettor: Dual

(rev/min)	Thrust (N)	Torque (N m)	Power (HP)	(kW)
3500	38			
4000	49	3.0	1.7	1.3
4500	59	3.7	2.3	1.7
5000	74	4.3	3.1	2.3
5500	88	5.3	4.1	3.0
6000	104	6.2	5.2	3.9
6500	119	7.3	6.7	5.0
7000	142	8.2	8.1	6.0
7500	157	9.8	10.3	7.7
7700	173	10.0	10.8	8.1

Date	Min	
15/08/78	30	Engine run for measurements with three wide chord tip propellers.

Time: 9 am
Ambient temperature: 8°C
Pressure: 1027.3 HPa
Propeller: 508 x 380 mm (wide chord tip)

(rev/min)	Thrust (N)	Torque (N m)	Power (HP)	(kW)
3500	40			
4000	50	3.2	1.8	1.3
4500	65	3.8	2.4	1.8
5000	81	4.8	3.4	2.5
5500	102	5.7	4.4	3.3
6000	124	6.4	5.4	4.0
6500	141	7.5	6.9	5.1
7000	159	8.8	8.6	6.4
7400	180	9.8	10.2	7.6

Ambient temperature: 8°C
Pressure: 1027.3 HPa
Propeller: 508 x 355 mm (wide chord tip)

(rev/min)	Thrust (N)	Torque (N m)	Power (HP)	(kW)
3500	38			
4000	50	2.9	1.6	1.2
4500	65	3.4	2.2	1.6
5000	84	3.9	2.7	2.0
5500	102	5.2	4.1	3.0
6000	124	6.2	5.2	3.9
6500	141	7.1	6.4	4.8
7000	164	8.4	8.3	6.2
7600	186	9.4	10.1	7.5

Date	Min	
15/08/78 Continued		Ambient temperature: 8°C Pressure: 1027.3 HPa Propeller: 508 x 330 mm (wide chord tip)

(rev/min)	Thrust (N)	Torque (N m)	Power (HP)	(kW)
3500	35			
4000	50	2.5	1.4	1.1
4500	59	3.2	2.0	1.5
5000	71	3.7	2.6	1.9
5500	88	4.3	3.4	2.5
6000	98	5.0	4.2	3.2
6500	122	5.9	5.4	4.0
7000	143	6.8	6.7	5.0
7500	164	8.0	8.4	6.3
8000	183	9.9	10.0	7.4
8150	186	9.1	10.4	7.8

17/08/78 16 Engine test.

Propeller: 508 x 380 mm (wide chord tip)

(rev/min)	THRUST (N)
3500	40
4000	52
4500	63
5000	80
5500	96
6000	113
6500	136
7000	156
7500	178
7800	186

Date	Min	
22/08/78		Engine fitted to XM-1A/2 with 508 x 380 mm propeller. Exhaust stubs remade.
23/08/78		Ignition mechanism reworked to extend retard position.
24/08/78	25	Aircraft vibration test.
	12	Aircraft vibration test.
	25	Aircraft vibration test.
25/08/78		Engine removed for mounting arrangement to be reinforced.
28/08/78		Silentbloc engine mounts fitted to aircraft XM-1A/2.

Date	Min	
29/08/78		Engine refitted to XM-1A/2.

Meteorological data

Time:	11 am	2 pm
Ambient temperature:	14.8°C	17.1°C
Pressure:	1021 HPa	1021 HPa

Time: 12 noon
Propeller: 508 x 380 mm (wide chord tip)

(rev/min)	Thrust (N)	Torque (N m)	Power (HP)	(kW)
3500	41			
4000	56	3.3	1.9	1.4
4500	66	3.8	2.4	1.8
5000	86	4.8	3.4	2.5
5500	98	5.6	4.3	3.2
6000	117	6.5	5.5	4.1
6500	141	7.7	7.1	5.3
7000	161	8.9	8.7	6.5
7500	185	9.9	10.4	7.8
8000	205	11.1	12.5	9.3

Time: 12.13 pm
Propeller: 508 x 355 mm (wide chord tip)

(rev/min)	Thrust (N)	Torque (N m)	Power (HP)	(kW)
3500	36			
4000	47	3.0	1.7	1.3
4500	62	3.4	2.2	1.6
5000	73	4.3	3.1	2.3
5500	88	5.0	3.9	2.9
6000	107	6.0	5.1	3.8
6500	126	7.1	6.4	4.8
7000	153	8.1	7.9	5.9
7500	176	9.3	9.8	7.3
8000	196	10.9	12.2	9.1

30/08/78	20	Vibration test.
	22	Vibration test.
06/09/78		Engine removed.
12/09/78		Engine refitted to XM-1A/2.
05/09/78	5	Vibration test.
	22	Vibration test.
14/09/78	27	System compatability test.

Date	Min	
18/09/78		Engine removed. Fitted to XM-1A/W1 with 508 x 380 mm propeller. New carburettor mounting bracket made.
22/09/78		Double interrupter fitted to ignition system. Advance - 3 mm before TDC. Retard - 0.508 mm before TDC. New carburettor mounting bracket fitted. Engine refitted to XM-1A/W1.
02/10/78		Engine run and ignition unit removed for checking.
03/10/78		Ignition refitted.
06/10/78	5	Ignition advance faulty.
10/10/78	4	Engine run for ignition test.
11/10/78	4	Engine run for ignition test and to adjust timing. Ignition unit removed to seal oil leak in coil.
17/10/78	7 23	Engine run at AD. Taxi trial at Edinburgh.
19/10/78	3 24	Engine run at AD A/W1 2 and A/W1 3. Flight trial. Crashed on applying power.
23/10/78		Engine removed from recovered airframe.
25/10/78		Ignition timing check. Crankshaft alignment check. New propeller fitted.
26/10/78	5 5	Engine run. Ignition system faulty. Engine run. Ignition system check.
05/11/78		Engine fitted to test rig for throttle servo response check.
05/12/78		Engine fitted to test rig for servo throttle response checks.
07/12/78	5	Engine run.
08/12/78	10	Engine run.
14/12/78	27	Engine run to check throttle servo response.
19/12/78	12	Engine run to check throttle servo response.
20/12/78	5	Engine run to check throttle servo response.
21/12/78	15	Engine run to check throttle servo response.
02/04/79	10	Manifold rubber fractured due to carburettor bracket misalignment resulting from crash. Replaced and corrected.
03/04/79	15	Engine run. Ignition faulty.
04/04/79	10	Engine run. Ignition faulty.

Date	Min	
10/04/79		Ignition disc slot widened to 0.031 inches. New timing ring fitted. Timing reset to retard 0.015° BTDC Advance 0.120° BTDC
11/04/79	10 25	Engine run and CDI power supply failed. Original power supply connected.

Time: 2 pm
Ambient temperature: 16°C
Pressure: 1025 HPa
Propeller: 508 x 380 mm

(rev/min)	Thrust (N)	Torque (N m)	Power (HP)	Power (kW)
3700	53	2.3	1.2	0.9
4600	89	3.6	2.3	1.7
5600	113	5.4	4.3	3.2
6500	160	7.7	7.0	5.2
7500	205	10.4	10.9	8.2
7800	222	10.8	11.9	8.9

Date	Min	
17/04/79	20	Engine test run to measure thrust.

Propeller: 508 x 380 mm
Ambient temperature: 19°C
Pressure: 1007 HPa

(rev/min)	Thrust (N)	
	Up	Down
3600	44	40
4500	76	71
5500	107	102
6600	151	151
7400	178	178
7800	205	205

Date	Min	
18/04/79		Fitted to XM-1A/5.
24/05/79	15	Engine run. Engine stopped when arming plug connected to switch on telemetry. RF interference. Telemetry antennae ground plane increased in area.
28/05/79	40	Engine run for system checks. Engine ran well but it missed every 5 to 10 s when ASI pressurised. Spark plug change did not clear fault.
29/05/79	10 35	Engine run for system checks, still a problem re ASI. Engine run for system checks, still a problem re ASI.
21/06/79	38	Aerial tests.

Date	Min	
26/06/79	26	Aerial tests.
27/06/79	28	Aerial tests. Screened ignition unit fitted.
05/07/79		Engine failed to run. Faulty optical coupler in CDI.
04/07/79		Ignition system faulty: replaced retard sensor. Repotted with screened pickup loom.
06/07/79	14	Engine ran then stopped. Faulty CDI.
11/07/79		CDI checked and fault corrected.
11/07/79	48	Engine run. Stalled at idle.
	14	Engine run. Stalled at idle.
12/07/79	26	Engine run. Stalled at idle.
	16	Engine run. Stalled at idle. Engine failed to restart.
13/07/79		Timing reset.
17/07/79	27	Engine run.
	23	Engine run.
18/07/79	25	Engine run. Smooth running. Easy start.
	16	Engine run.
19/07/79		Engine removed from XM-1A/5. Control linkage refitted. Intake manifold rubbers renewed. Engine refitted to XM-1A/5.
10/08/79	5	Engine run.
15/08/79	40	Engine run for telemetry checks.
	37	Engine run for telemetry checks.
04/10/79	25	Engine run for telemetry checks. Engine cut not serviceable.
11/10/79	10	Engine run to check fail safe mode. Plugs replaced. RH manifold rubber replaced.
15/10/79	35	Engine run for fail safe mode test.
24/10/79	30	Engine run 10 times to test engine cut out. Satisfactory Ignition leads replaced - Shielding frayed.
30/10/79		Timing checked.

	Before TDC	On for
Retard	0.015°	0.007°
Advance	0.126°	0.036°

14/11/79	10	Engine run for test rig checks.

Date	Min	
16/11/79	20	Engine test run.

Time: 9.15 am
Ambient temperature: 15°C
Pressure: 1016 HPa
Propeller: 508 x 380 mm

(rev/min)	Thrust (N)	Torque (N m)	Power (HP)	(kW)
7700	214	11.1	12.0	8.9
6500	158	7 9	7.3	5.4
5700	121	6.1	4.9	3.7
4900	84	4.6	3.1	2.3
3500	49	2.3	1.1	0.8
4700	78	4.1	2.7	2.0
5500	105	5.5	4.2	3.1
6400	153	8.0	7.1	5.3
7700	214	11.1	12.0	8.9

Engine start was satisfactory.
Smooth running.

Date	Min	
04/02/80	10	Engine run to test new CDI box.
05/02/80	10	Engine run to test spare CDI box.
16/09/80	30	Engine run with zero incidence propeller test. Idle revolutions per minute 1700, max revolutions per minute 9500.
19/02/81		Engine fitted to XM-1A/2.
03/03/81	15	Engine run 1600 to 7600 rev/min.
	25	Engine run 1600 to 7600 rev/min.
05/11/81		Engine failed to start - internal battery unserviceable.
06/11/81	50	Engine run on shore supply to retune - 2000 to 7700 rev/min.
12/11/81	12	Engine run for aerial tests.
18/11/81	8	Taxi trial, max revolutions per minute 7800.
14/12/81	5	Engine run for system checks.
	5	Engine run for system checks.
15/12/81	6	Engine run at AD.
	5	Taxi trial at Edinburgh.
	14	Flight trial A/2 No. 1 9 min airborne.
02/04/82	7	Engine run for system check.
07/04/82	5	Engine run for systems check.
	25	Flight trial A/2 No. 2 16 min airborne.

Date	Min	
11/06/82	14	Engine run for system checks.
30/06/82	9	Flight trial A/2 No. 3 Airborne 2 min. Engine cut in flight.
05/07/82	40	Engine run and retuned.
06/07/82	20	Retuned. 2200 to 7600 rev/min.
12/07/82	20	Flight trial A/2 No. 4. Engine cut. Hard landing.
15/07/82	15	Engine at AD. Engine removed from XM-1A/2.

Total running time of engine, serial number 2, was approximately 26 h

VIII.3 Third Dyad engine, Serial No. 3

Date	Min	
22/01/79		Engine with ignition received.
23/02/79		Assembly completed.
02/03/79		Mounted on test rig with Herbrandson ignition system. Failed to start - timing disc found to be 40° misaligned. Reset correctly.
05/03/79		Engine with Herbrandson ignition system installed on test rig.
05/03/79	7	Engine ran satisfactorily.
	8	Engine ran satisfactorily.
	15	Engine ran satisfactorily.
	25	Engine ran satisfactorily.
07/03/79	35	Engine ran satisfactorily.
08/03/79	20	Engine ran well. Carburettors adjusted.
16/03/79	7	Engine ran well. WSRL CD ignition was system fitted.
21/03/79	83	Engine with 508 x 330 mm propeller run for test of fibreglass fuel tank.

(rev/min)	Consumption
6300	2.6 L/h
6200	2.4 L/h
5200	1.5 L/h
8400	8.6 L/h

22/03/79		Ignition ring fixing screws vibrated loose. Ring replaced with less hole clearance.
09/05/79	10	Engine run.

Date	Min	
11/05/79	50	Engine run and retuned. Engine test run.

Ambient temperature: 15°C
Pressure: 1020 HPa
Propeller: 508 x 380 mm

(rev/min)	Thrust N Up	Down	Torque (N m)	Power (HP)	(kW)
3500	40	40	2.0	1.0	0.7
4800	64	64	3.4	2.3	1.7
5500	91	90	4.8	3.7	2.8
6500	136	133	6.9	6.3	4.7
7600	182	178	9.3	9.9	7.4
8400	222		11.6	13.7	10.2

Date	Min	
14/05/79		Ignition lead potted. Timing checked. New plugs (XEJ6 fitted).
29/10/79		Timing check.

	Before TDC	On for
Retard	0.015°	0.007°
Advance	0.130°	0.060°

Date	Min	
31/10/79		Engine fitted to XM-1A/5.
09/11/79	15	Engine run. 1900 to 8000 rev/min measured.
	10	Engine run. 1600 to 8000 rev/min Kraft control.
05/12/79	15	Engine run for range control checks.
07/12/79	30	Taxi trials.
12/12/79	20	Engine run for recorder calibration.
14/12/79	12	Engine run for recorder calibration.
19/12/79	42	Taxi trials. New propeller fitted. Mounting blocks replaced.
	5	Engine run.
20/12/79	10	Taxi trials. RH manifold rubber was unsatisfactory.
21/01/80		Manifold rubbers replaced. Carburettor linkage & plate reworked.
05/02/80	10	Engine run.
	10	Engine run.
13/02/80	10	Taxi trials.
15/02/80	30	Engine run for range control test.

Date	Min	
19/02/80	15	Engine run for range control test - throttle. Mech throttle: 1700 to 8100 rev/min Kraft control: 3800 to 8100 rev/min Link refitted. Kraft control: 1600 to 8100 rev/min Runs OK on retard at low revs.
21/02/80	5	Engine run - throttle link and servo disc replaced. 1600 to 8100 rev/min measured.
22/02/80	10	Engine run for ASI - recorder calibration.
27/02/80	15	Taxi test at Edinburgh. Flight trial A/5 No. 1 1 min airborne.
04/03/80	6	Engine run, idle revolutions per minute 1400 max 8000. Mounting blocks replaced. CDI lead repotted.
05/03/80	10 10	Taxi test at Edinburgh. Flight trial A/5 No. 2 and A/5 No. 3 Airborne 5 min each flight.
19/03/80	25	Engine run. 1800 to 8100 rev/min. Mounting blocks fitted. Issue 2 mounting plate fitted. 3/16 inches dia PVC fuel lines fitted.
31/03/80		Neoprene fuel lines fitted.
15/04/80	12	Engine run - cal record 1600 to 8000 rev/min.
29/04/80	18	Flight trial A/5 No. 4 - crashed on landing.
26/05/80		New propeller fitted. New fuel lines fitted.
21/07/80	10	Engine run. 2000 to 5600 rev/min port cylinder not firing.
22/07/80	 20	CDI box tested. Engine run. Retuned 1800 to 7800 rev/min. Shore supply.
23/07/80	5	Engine run - internal supply 1800 to 8000 rev/min.
20/11/80	10 40	Engine run - zero incidence propellor. Engine run for aerial tests.
04/02/81	9 5	Engine run for recorder calibration. Engine run.
11/02/81	10 1	Taxi trial at Edinburgh. Flight trial A/5 No. 5 Crashed after take off.
19/02/81		Port cylinder removed. Checked. Cleaned. Carburettors cleaned. Optical transducer and lead renewed. New propeller fitted.
24/02/81	5	Engine run 1600 to 8000 rev/min.

Date	Min	
01/04/81		508 x 355 mm propeller fitted.
	40	Engine test run.

Time: 2.30 pm
Ambient temperature: 27°C
Pressure: 1014 HPa
Propeller: 508 x 355 mm

(rev/min)	Thrust (N)	Torque (N m)	Power (HP)	(kW)
8100	215	10.7	12.1	9.1
7500	180	9.1	9.6	7.1
6600	135	7.1	6.5	4.9
5500	98	4.9	3.8	2.8
4600	69	3.6	2.3	1.7
3600	42	2.2	1.1	0.8
4500	64	3.4	2.2	1.6
5400	92	4.7	3.5	2.7
6400	129	6.7	6.0	4.5
7400	171	8.9	9.2	6.9
8100	215	10.7	12.1	9.1

Date	Min	
02/04/81		Engine fitted to XM-1A/3.
29/04/81	45	Engine run for system checks. Stalled: failed to restart. Engine removed from XM-1A/3. Engine ran well on test rig 1500 to 8100 rev/min. Plugs renewed XEJ6.
30/04/81	25	Engine run for system check on shore supply. Stalled: engine cut removed and replaced, running well -1800 to 8100 rev/min.
04/05/81	10	Engine run for fuel flow tests. Engine cut.
	25	Engine run for fuel flow tests.
05/05/81	20	Engine run for fuel flow tests. Engine cut twice.
07/05/81	17	Engine run for fuel flow tests.
12/05/81	10	Engine run for aerial tests. Engine cut twice.
	15	Engine run for system check correct.
13/05/81	10	Engine run for aerial tests. Engine cut.
27/05/81	10	Engine run for aerial tests. Engine cut system renewed.
28/05/81	5	Engine run for aerial tests.
02/06/81	20	Engine run for aerial tests.
03/06/81	10	Engine run for aerial tests.

Date	Min	
12/06/81	20	Engine run for aerial tests.
17/06/81	15	Engine run for aerial tests.
22/06/81	2	Engine cut system tested and it worked correctly.
23/06/81		Engine removed from XM-1A/3 and refitted.
27/07/81	7	Engine run 1700 to 8000 rev/min.
12/08/81	13	Engine run for recorder calibration - 1500 to 7800 rev/min.
28/08/81	15	Taxi trial with 1 airborne circuit. Flight trial A/3 No. 34.
07/09/81	20	Preflight check 1500 to 8100 rev/min. Flight trial A/3 No. 35.
11/09/81	10	Engine ran 1500 to 8000 rev/min. Flight trial A/3 No. 36.
16/09/81	8	Engine ran 1500 to 8100 rev/min. Flight trial A/3 No. 37.
17/09/81	9	Engine ran 1500 to 8100 rev/min. Flight trial A/3 No. 38.
	7	Engine ran 1500 to 8000 rev/min. Flight trial A/3 No. 39.
18/09/81	5	Engine run 1500 to 8100 rev/min. Flight trial A/3 No. 40.
29/09/81	16	Engine run 1500 to 8100 rev/min. Flight trial A/3 No. 41.
28/10/81	18	Engine run for temperature tests. Temperatures on cylinder after running for 15 min were 104°C near spark plug end and manifold, 161°C mid way along cylinder and 165°C a fifth of the distance from the plug and base of the cylinder.
29/10/81	12	Flight trial A/3 No. 42.
05/11/81	14	Flight trial A/3 No. 43. Airborne 7 min.
13/11/81	3	Engine run satisfactory.
20/11/81	22	Flight trial A/3 No. 44 - photographic record.
27/01/82	2	Engine run for sound level test. CDI unserviceable.

Date	Min	
03/02/82	2	Engine run satisfactory.
	5	Engine run at 8000 rev/min for sound level tests.

Sound level 1 m from engine

(rev/min)	Sound level (dB)
8000	130 +
5500	118
2000	112

Distance (m)	Sound level (dB)
1	130
2	127
4	124
8	121
16	118
32	115
64	112

15/03/82	6	System test. 1800 to 8200 rev/min.
17/03/82	22	Flight trial A/3 No. 45.
18/03/82	16	Flight trial A/3 No. 46.
06/04/82	15	Flight trial A/3 No. 47.
15/06/82	5	Engine run 1800 to 8000 rev/min.
24/06/82	5	Taxi trial.
	5	Engine run.
	10	Taxi trial.
25/06/82	22	Flight trial A/3 No. 48. Airborne 14 min. Removed from XM-1A/3.

Total running time of engine, serial number 3, was approximately 22 h.

VIII.4 Fourth Dyad engine, Serial No. 4

Date	Min	
15/07/80		Assembly completed. Walbro carburettors fitted. Timed retard 2.37° BTDC Advance 28° BTDC
	2	Engine run.
21/07/80	30	Engine run and tuned revolutions per minute 7800 max 2700 idle.
22/07/80	25	Engine run with new CDI box. Carburettor manifold neoprene tubes replaced.

23/07/80 Carburettor butterfly holes sealed.

24/07/80 30 Engine run and retuned revolutions per minute 7800 max 1700 idle.

Date Min

Time: 9.30 am
Ambient temperature: 10°C
Pressure: 1029 HPa
Propeller: 508 x 380 mm

(rev/min)	Thrust (N)	Torque (N m)	Power (HP)	(kW)
7800	211	11.5	12.6	9.4
7500	189	10.4	11.0	8.2
6700	153	8.4	7.9	5.9
5700	109	6.0	4.8	3.6
4500	64	3.9	2.5	1.8
3500	42	2.5	1.2	0.9
4400	62	3.7	2.3	1.7
5400	100	5.7	4.3	3.2
6400	140	7.5	6.8	5.0
7400	180	10.0	10.4	7.7
7800	211	11.5	12.6	9.4

05/03/81 Engine fitted to XM-1A/3.

06/03/81 Engine removed from XM-1A/3.

Total running time of engine, serial number 4, was approximately 1½ h.

APPENDIX IX

NOSLEN FOUR PROTOTYPE ENGINE - RUNNING HISTORIES

Weight of engine 1860 gm
Fuel mixture 77% methanol, 3% nitro-methane, 20% oil.

20/10/75 Engine run for approximately 15 min. During that time it stopped of its own accord on four occasions probably due to over rich mixture and low revolutions per minute. It was restarted each time by hand.

22/10/75 The two forward cylinders were removed for inspection. The lower connecting rod bearings showed signs of excessive wear. The engine was returned to the manufacturer for attention.

Engine was returned to us within a few days having had phosphor-bronze bearings fitted to lower connecting rod ends.

Engine run for 3 min at low revolutions per minute.

17/11/75 Engine run at varying speeds for 5, 5 and 6½ min.

05/01/76 Engine run for a total of 30 min at varying speeds.

06/01/76 Engine run for a short period to check thrust

Propeller: 432 mm x 152 mm (17 x 6 inches)

(rev/min)	Thrust (N)
4300	22
7400	65
8300	81
9000	87

09/01/76 Engine run to check fuel consumption.

10 min run at 7600 rev/min)
2 min run at 4000 rev/min) Fuel used 640 mL
6 min run at 6000 rev/min)

Engine run for 3 min to check revolution counter.

19/08/76 Engine run for 20 min.

Propeller 432 mm x 152 mm (17 x 6 inches).

(rev/min)	Thrust (N)	Torque (N m)	Power	
			(HP)	(kW)
9000	100	2.7	3.4	2.5

Engine still fairly stiff to turn over.

29/04/77 Engine run for 15 min.

Propeller 432 mm x 152 mm (17 x 6 inches).

(rev/min)	Torque (N m)	Power (HP)	(kW)
8800	2.6	3.2	2.4

04/05/77 Engine run at varving speeds for approximately 2 h.

24/05/77 Engine run for 45 min.

Time:	10.30 am	11.30 am
Ambient temperature:	13.8°C	14.5°C
Pressure:	1006 HPa	1006 HPa

(rev/min)	Thrust (N)	Torque (N m)	Power (HP)	(kW)	Propeller size (mm)	inches)
8 900	95	2.54	3.2	2.4	432 x 152	17 x 6
10 000	92	2.26	3.2	2.4	405 x 152	16 x 6
9 900	86	2.48	3.5	2.6	380 x 203	15 x 8
13 400	69	1.52	2.9	2.1	330 x 140	13 x 5½

10/06/77 Engine run for 8 min.
Propeller: 356 mm x 152 mm (14 x 6 inches).

(rev/min)	Thrust (N)	Torque (N m)	Power (HP)	(kW)	Time (min)	Fuel used (mL)	Throttle setting
8 000	48	1.30	1.5	1.1	4.0	200	1/2
8 500	56	1.58	1.9	1.4	3.3	200	3/4
10 800	86	2.54	3.9	2.9	-	-	Full

The engine stopped suddenly. It was dismantled for inspection and the bearing cap from No. 2 lower connecting rod end was found to have separated from the rod, presumably due to the 2 retaining screws becoming loose thereby allowing the heads to make contact with the crankcase and shear off. Engine sent to workshop for repair.

11/11/77 Engine run for 5, 2 and 4 min at varying speeds.

17/11/77 Engine run for 3 min at varying speeds, when suddenly it stopped. Engine was dismantled and again the bearing cap of No. 2 connecting rod was found to be loose in the crankcase with the screws broken off as before. As space was insufficient to allow the fitting of shakeproof washers or locking wire to the connecting rod screws, the grade of 'loctite' was changed and the screws were staked.

Total engine running time was approximately 5 h.

APPENDIX X

ESTABLISHMENT TITLES

X.1 DSTO Establishments

DSTO Defence Science and Technology Organisation of Australian Department of Defence

WSRL Weapon Systems Research Laboratory. One of the laboratories of DSTO located at Salisbury in South Australia.

AD Aeroballistics Division renamed Weapons Division (WD) in June 1986. One of the four Divisions of WSRL

FE Field Experiments Group renamed Weapon Experiments Group in June 1986. One of the Groups of AD now WD.

AES Aeroballistics Engineering Section. The engineering support section of AD and now part of Weapon Experiments Group.

WSD Weapon Systems Division renamed Combat Systems Division and one of the Divisions of WSRL.

AEL Advanced Engineering Laboratory. One of the laboratories at DSTO Salisbury but disbanded in the reorganisation in December 1987.

CTH Central Test House renamed Environmental Engineering Group formerly part of AEL and now in Support Service Organisation at Salisbury.

WRE Weapons Research Establishment - an Establishment at Salisbury now divided into four independent laboratories colocated at Salisbury and collectively designated as DSTO, Salisbury

X.2 RAAF Establishment

Edinburgh RAAF Base, Edinburgh near Salisbury in South Australia from which all liftoff and flights trials took place.

APPENDIX XI

ABBREVIATIONS

ASI	air speed indicator
CDI	capacitor discharge ignition
L/h	litres per hour
L/HP/h	litres per horsepower per hour
RFI	radio frequency interference
RPV	remotely piloted vehicles
TDC	top dead centre
BTDC	before top dead centre

DISTRIBUTION

	Copy No.
DEPARTMENT OF DEFENCE	
Defence Science and Technology Organisation	
Chief Defence Scientist	1
Assistant Chief Defence Scientist (Policy)	
Assistant Chief Defence Scientist (Operations)	
Director General External Relations	
Director General Science Technology Programs	
Special Projects Officer, Forward Planning Science	
Counsellor, Defence Science, London	Cnt Sht Only
Counsellor, Defence Science, Washington	Cnt Sht Only
Weapons Systems Research Laboratory	
Director, Weapons Systems Research Laboratory	2
Superintendent, Combat Systems Division	3
Superintendent, Propulsion and Ballistics Division	4
Superintendent, Weapons Division	5
Head, Weapon Experiments Group	6 - 7
Head, Weapon Dynamics Group	8
Head, Weapon Guidance and Control Group	9
Head, Weapon Seekers Group	10
C. Marston, Systems Modelling Group	11 - 12
Author	13
Aeronautical Research Laboratories	
Director, Aeronautical Research Laboratories	14
Superintendent, Aerodynamics and Aeropropulsion Division	15
Principal Engineer, Air Systems Engineering	16
Principal Officer, Propulsion Mechanics Group	17
B.G. Catchpole, Propulsion Mechanics Group	18

Surveillance Research Laboratory	
Director, Surveillance Research Laboratory	19
Superintendent, Optoelectronics Division	20
Principal Engineer, Mechanical Design and Development	21
Libraries and Information Services	
Librarian, Technical Reports Centre, Defence Central Library, Campbell Park	22
Document Exchange Centre Defence Information Services Branch for:	
Microfiche copying	23
United Kingdom, Defence Research Information Centre	24 - 25
United States, Defense Technical Information Center	26 - 37
Canada, Director, Scientific Information Services	38
New Zealand, Ministry of Defence	39
National Library of Australia	40
Defence Science and Technology Organisation Salisbury	
Main Library	41 - 42
WD Library	43 - 44
Library, Aeronautical Research Laboratories	45
Library, Materials Research Laboratories	46
Library, Defence Science and Technology Organisation Sydney	47
Library, Aircraft Research and Development Unit	48
Library, Office of Defence Production	49
Library, DSD, Melbourne	50
Joint Intelligence Organisation (DSTI)	51
Army Office	
Scientific Advisor - Army	52
Director General, Army Development (NSO), Russell Offices for ABCA Standardisation Officers	
UK ABCA representative, Canberra	53
US ABCA representative, Canberra	54

DOCUMENT CONTROL DATA SHEET

Security classification of this page : UNCLASSIFIED

1 DOCUMENT NUMBERS

AR Number : AR-005-348

Series Number : WSRL-0566-TM

Other Numbers :

2 SECURITY CLASSIFICATION

a. Complete Document : Unclassified

b. Title in Isolation : Unclassified

c. Summary in Isolation : Unclassified

3 DOWNGRADING / DELIMITING INSTRUCTIONS

4 TITLE

ENGINES FOR MINI-RPV XM-1A

5 PERSONAL AUTHOR (S)

E.H. Barnard-Brown

6 DOCUMENT DATE

January 1988

7 7.1 TOTAL NUMBER OF PAGES 105

7.2 NUMBER OF REFERENCES 9

8 8.1 CORPORATE AUTHOR (S)

Weapons Systems Research Laboratory

8.2 DOCUMENT SERIES and NUMBER

Technical Memorandum 0566

9 REFERENCE NUMBERS

a. Task :

b. Sponsoring Agency :

10 COST CODE

330466

11 IMPRINT (Publishing organisation)

Defence Science and Technology Organisation Salisbury

12 COMPUTER PROGRAM (S) (Title (s) and language (s))

13 RELEASE LIMITATIONS (of the document)

Approved for Public Release.

Security classification of this page : UNCLASSIFIED

Security classification of this page : UNCLASSIFIED

14 ANNOUNCEMENT LIMITATIONS (of the information on these pages)

No limitation

15 DESCRIPTORS		16 COSATI CODES
a. EJC Thesaurus Terms	Remotely piloted vehicles Reciprocating engines Small engines	0097L 0051C
b. Non - Thesaurus Terms	Kolbo D238 engine Dyad 160 engine	

17 SUMMARY OR ABSTRACT
(if this is security classified, the announcement of this report will be similarly classified)

There were very few light-weight reciprocating engines in the five to ten horsepower range existing in Australia or overseas when a programme of research and exploratory development of the techniques required to operate unmanned airborne vehicles from a remote base station started in 1975. Those that did were generally single cylinder engines which are difficult to balance over the speed range necessary for mini remotely piloted vehicle (RPV) operation. A twin cylinder Kolbo D238 engine and a larger Herbrandson Dyad 160 engine were flown. When fitted with a locally developed capacitor discharge ignition system, both these engines performed reliably in flight trials of the mini-RPV XM-1A. However, the Kolbo engine had insufficient power for aicraft with a take-off mass of more than about 35 kg.

This memorandum records the experience and test results gained at Weapons Systems Research Laboratory (WSRL) on small engines from its mini-RPV programme conducted during 1975 to 1981.

Security classification of this page : UNCLASSIFIED

The official documents produced by the Laboratories of the Defence Research Centre Salisbury are issued in one of five categories: Reports, Technical Reports, Technical Memoranda, Manuals and Specifications. The purpose of the latter two categories is self-evident, with the other three categories being used for the following purposes:

Reports	:	documents prepared for managerial purposes.
Technical Reports	:	records of scientific and technical work of a permanent value intended for other scientists and technologists working in the field.
Technical Memoranda	:	intended primarily for disseminating information within the DSTO. They are usually tentative in nature and reflect the personal views of the author.